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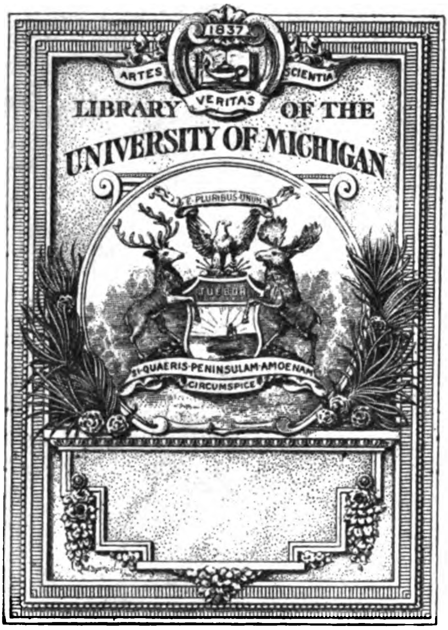

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 448

GEOLOGY AND MINERAL RESOURCES OF THE NIZINA DISTRICT, ALASKA

BY
FRED H. MOFFIT
AND
STEPHEN R. CAPPS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1911

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PREFACE.

By Alfred H. Brooks.

The completion in 1908 of the reconnaissance surveys[a] of the two copper belts lying north and south of the Wrangell Mountains paved the way for more detailed investigations. As the southern or Chitina copper belt will be the first one to be developed, it was appropriate to begin the detailed investigation in this field. The funds available for this work made it possible to survey only a part of the Chitina belt, and after careful consideration it was decided to take up the work in the Nizina district. This conclusion was based on three considerations: (1) The information available indicated that the Nizina district afforded the best opportunities for solving the general geologic problems relating to the entire copper belt; (2) the mining developments of this part of the district were more extensive than elsewhere in the belt, which gave both better opportunities for observations on the occurrence of the ores and greater promise of soon reaching a productive basis; (3) investigation of this field made it possible to cover a placer district long productive in a small way and giving promise of larger output.

The descriptions set forth in this report apply to only about one-fourth of the Chitina copper belt, but the conclusions advanced as to occurrence of the ores will, it is believed, have value to the entire district. If the developments in the Chitina Valley continue, as is expected, further surveys will be undertaken as soon as circumstances permit.

The cost of detailed geologic maps is much increased by the fact that they must be preceded by detailed topographic surveys. The Nizina region was surveyed by D. C. Witherspoon in 1908, and the resulting map, which is an excellent piece of work done under very adverse conditions, accompanies this report (Pl. II, in pocket) and adds much to its value.

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[a] Moffit, F. H., and Maddren, A. G., The mineral resources of the Kotsina-Chitina region, Alaska: Bull. U. S. Geol. Survey No. 374, 1909; Moffit, F. H., and Knopf, Adolph, The mineral resources of the Nabesna-White River district: Bull. U. S. Geol. Survey No. 417, 1910.

The general geology of this district as set forth in the report bears testimony to the accuracy of the observations and deductions of the earlier workers in this field. It is a significant fact that the stratigraphic subdivisions, suggested by Oscar Rohn, who did the pioneer work in this field, have found acceptance in the present analysis of the geologic sequence.

The most important conclusion bearing on the economic geology here presented is the fact that the copper-ore bodies appear to occur chiefly along a system of cross fractures which are at approximately right angles to the greenstone-limestone contact. These fractures occur along well-defined faults, at least one of which has been traced for a long distance. This may apply to the entire Chitina district and is worthy of consideration by the prospector.

These investigations also appear to indicate that the copper deposits are by no means confined to the immediate vicinity of the limestone-greenstone contact, as has usually been supposed. Though the most promising ore bodies thus far found do occur in this contact, evidence of strong mineralization has been found at a considerable distance from it. Another important fact brought out by this investigation is the occurrence of auriferous deposits in the Kennicott formation (Jurassic).

This report, although far more complete than any other report previously published on the district, is by no means exhaustive. With the progress of mining many facts will be ascertained which will make possible more definite statements on the geology of the mineral deposits. If the district develops into a great copper producer, a detailed study of the mining geology should be undertaken similar to those made of many of the mining camps of the Western States.

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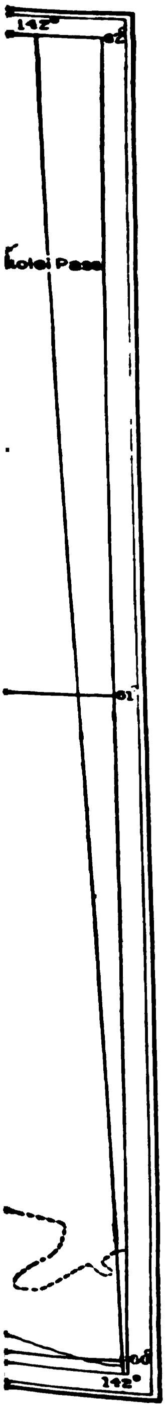
PLATE I



L MAP.

GEOLOGY AND MINERAL RESOURCES OF THE NIZINA DISTRICT, ALASKA.

By Fred H. Moffit and Stephen R. Capps.

INTRODUCTION.

LOCATION AND AREA.

The Nizina district takes its name from Nizina River, a northern branch of Chitina River, and lies in the eastern part of the Copper River drainage basin. Its position with reference to the coast and the Canadian boundary is shown on Plate I, opposite. That portion of it to which the following descriptions are confined is included between parallels 61° 12′ and 61° 37′ north latitude and meridians 142° 22′ and 143° west longitude and is represented on the Nizina special map. (See Pl. II, in pocket.) The area mapped, however, is irregular in outline and only 300 square miles in extent, so that it comprises little more than one-half of the quadrangle indicated.

OUTLINE OF GEOGRAPHY, GEOLOGY, AND EXPLORATION.

Chitina River rises in the high snow-covered mountains northwest of Mount St. Elias and adjacent to the international boundary line and flows westward between the Chugach and the Wrangell mountains till it unites with Copper River at a point 100 miles from the coast. (See Pl. I.) Most of its waters, however, are derived through its northern tributaries from the snow fields of the Wrangell group. Nizina River is the largest of these tributaries. It drains the southeastern part of the Wrangell Mountains and a small part of the area between Chitina River and the head of White River. From its principal source in Nizina Glacier it flows southward for 15 miles and then turns abruptly to the west and continues in that direction 20 miles farther before joining the Chitina. It therefore has a length of 35 miles, all minor curves and irregularities of its course being disregarded. The big westward bend of the river lies almost in the center of the area covered by the Nizina special map.

The two branches of the Nizina, with Chitistone and Kennicott rivers, contribute much the greater part of its waters. It is therefore chiefly of glacial origin. All these streams are swift and heavily laden with glacial débris. They have floored their valleys with broad gravel flats, over which they migrate from side to side, sometimes in a single channel, sometimes in a network of channels, and, besides building up their flood plains by the addition of new material, they are continually cutting away and redepositing the material already laid down. The principal small streams shown on the Nizina special map are McCarthy Creek, a tributary of Kennicott River, and Dan, Chititu, and Young creeks, eastern tributaries of Nizina River. Their valleys do not show such profound glacial erosion as the main streams, for the ice masses that occupied them were smaller, yet they nevertheless underwent extensive glaciation. All are characterized by broad, open valleys at their heads and by rock canyons in their lower courses.

The Wrangell Mountains, although a more or less distinct group, merge into the St. Elias Range on the southeast and are not there sharply defined from them. They are limited on the south and west and partly on the north by the valleys of Chitina and Copper rivers, and are separated from the Nutzotin Mountains on the northeast by a depression extending from the head of Copper River to the head of White River. The group trends in a northwest-southeast direction and its length is approximately double its width. Its greatest diameter is about 100 miles. Half a dozen or more peaks of unusual beauty and size, ranging in height from 12,000 to 16,200 feet, rise above the rugged snow-covered mass about them, and from one of these, Mount Wrangell, the group received its name. The Wrangell Mountains were formed by the erosion of a great mass of Tertiary and Recent lavas piled up on an older surface of very considerable relief and having its greatest development in the neighborhood of Mount Wrangell and Mount Sanford. The southeastern limit of these younger flows is probably somewhere in the vicinity of Skolai Pass and Chitistone River, although it is possible that they may extend still farther to the east. Thus the Wrangell Mountains consist essentially of lava flows and are distinct in their origin from the other mountains about them, all of which are made up principally of deformed sedimentary beds. The area shown on the Nizina special map is on the border line between the volcanic flows of the Wrangell Mountains on the northwest and the older sedimentary formations of the Chugach and St. Elias mountains on the south and southeast, but the rock formations developed in the area are mostly of sedimentary origin.

The formations represented on the accompanying geologic map (Pl. III, in pocket) are shown in the section forming figure 1. At the base is the Nikolai greenstone, made up of a great but unknown thickness of basaltic lava flows, many of which are amygdaloidal. On the top of these flows rests the Chitistone limestone, which was deposited without any interruption of structural uniformity between it and the underlying rocks. Its thickness exceeds 3,000 feet. The lower part of the Chitistone formation consists of thick, massive beds of gray limestone, but toward the top the limestone beds become thinner and small shale beds appear in increasing amount till they finally predominate. The Chitistone limestone thus passes by transition through thin-bedded shales and limestones into a black shale with only occasional thin limestone beds. Much of the shale was removed by erosion before the deposition of the succeeding formation, so that its thickness, though in doubt, can not be less than several thousand feet. Both the Chitistone limestone and the conformably overlying shales (McCarthy shale) are of Upper Triassic age.

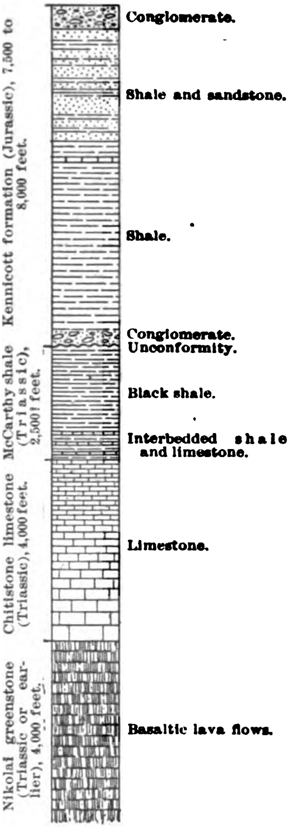

Kennicott formation (Jurassic), 7,500 to 8,000 feet.
McCarthy shale (Triassic), 2,500? feet.
Chitistone limestone (Triassic), 4,000 feet.
Nikolai greenstone (Triassic or earlier), 4,000 feet.
Conglomerate.
Shale and sandstone.
Shale.
Conglomerate.
Unconformity.
Black shale.
Interbedded shale and limestone.
Limestone.
Basaltic lava flows.

FIGURE 1.—Columnar section showing the formations represented on the geologic map of the Nizina district.

A period of uplift and erosion took place after the Triassic black shales were laid down and was not terminated till Upper Jurassic time, when deposition began once more. On the upturned edges of the Nikolai greenstone, the Chitistone limestone, and the overlying Triassic shales a great thickness of Upper Jurassic sediments (Kennicott formation) was deposited. They consist of conglomerate, sandstone, and black shale, but the shale predominates greatly over the conglomerate and the sandstone. The Jurassic sediments attain a thickness of at least 7,500 feet. They are the youngest of the bed-rock formations exposed within the mapped area. The later deposits consist of Quaternary sands, gravel, and silt, most of which are intimately connected in origin with the recent glaciation of the country.

The Nizina district has been the scene of igneous activity from Paleozoic time to the present. A great quantity of quartz diorite porphyry in the form of sills and dikes was intruded into the Jurassic rocks, but for some reason these intrusives rarely appear in the underlying formations. In some places the porphyritic intrusives are so extensively developed that they predominate over the shale, and the shale appears only as great black masses caught up in the light-colored intrusive rock.

Folding in greater or less degree has taken place in all the formations mentioned, but is far more pronounced in the older ones, particularly the Triassic shales, than in the Jurassic sediments. Within the area of the Nizina special map the greenstone, limestone, and shale formations dip rather steeply to the northeast. The Jurassic rocks, on the other hand, are tilted to the southwest or lie in broad, flat folds. All have been faulted and show local displacements of very considerable extent.

The earliest references to the geology of the Chitina Valley are found in the accounts of exploring expeditions made by Allen in 1885 and by Schwatka and Hayes in 1891. Such accounts, from the nature of the expeditions, could give only very incomplete information. The investigations by Rohn in 1899, however, laid the foundations of our present knowledge of the geology of the region. He recognized the formations that have been described and proposed the names Nikolai, Chitistone, and Kennicott. He also applied the name McCarthy Creek shale to the shale formation overlying the Chitistone limestone; but this was not adopted by Schrader and Spencer in their later work, since they believed that the shale should be divided into a number of formations.[a]

In 1900 Schrader and Spencer carried on a much more extended investigation of the geology and mineral resources of the Chitina Valley, and at the same time a topographic reconnaissance map was made by Gerdine and Witherspoon which was used as a base for the geologic map. Two years later (1902) Mendenhall visited the Kotsina and the Elliott Creek copper prospects, in the western part of the Chitina Valley, and published also some brief statements concerning the Nizina gold placers, although he had no opportunity to examine them in person. No further geologic work in the Chitina region was undertaken by the Federal Government till 1907, when interest in the copper resources of the country led to an examination by Moffit and Maddren of all the copper prospects in the valley, which resulted in some additional information concerning its geology and the occurrence of both copper and gold. The importance of the district led to the preparation of the Nizina special map by Witherspoon in 1908 and to the detailed geologic investigations in 1909, whose results are described in this report.

Many notes on the copper prospects, particularly the Bonanza mine, have appeared in the daily press and in mining magazines, and although most of them had only a temporary value as news a few are permanent contributions to the literature. An incomplete list of papers on the district follows:

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[a] Schrader, F. C., and Spencer, A. C., The geology and mineral resources of a portion of the Copper River district, Alaska: Special publication U. S. Geol. Survey, 1901, note at bottom of page 32.

ALLEN, Lieut. HENRY T. Report of an expedition to the Copper, Tanana, and Koyukuk rivers, in the Territory of Alaska, in the year 1885. Washington, Government Printing Office, 1887.

HAYES, C. WILLARD. An expedition through the Yukon district: Nat. Geog. Mag., vol. 4, 1892, pp. 117-162.

ROHN, OSCAR. A reconnaissance of the Chitina River and Skolai Mountains: Twenty-first Ann. Report U. S. Geol. Survey, pt. 2, 1900, pp. 393-440.

SCHRADER, FRANK C., and SPENCER, ARTHUR C. The geology and mineral resources of a portion of the Copper River district, Alaska: Special publication of the U. S. Geol. Survey, 1901.

MENDENHALL, WALTER C., and SCHRADER, FRANK C. The mineral resources of the Mount Wrangell district, Alaska: Prof. Paper U. S. Geol. Survey No. 15, 1903.

MENDENHALL, WALTER C. Geology of the central Copper River region, Alaska: Prof. Paper U. S. Geol. Survey No. 41, 1905.

MOFFIT, FRED H., and MADDREN, A. G. The mineral resources of the Kotsina and Chitina valleys, Copper River region: Bull. U. S. Geol. Survey No. 345. 1908, pp. 127-175. (This is a preliminary statement of results published in a more complete form in Bulletin 374.

KELLER, HERMAN A. The Copper River district, Alaska: Eng. and Min. Jour., vol. 85, No. 26, June, 1908, pp. 1273-1278.

MOFFIT, FRED H., and MADDREN, A. G. The Kotsina-Chitina region, Alaska: Bull. U. S. Geol. Survey No. 374, 1909.

The field work on which the present report and the geologic map are based was done between July 1 and September 10, 1909, or in a little less than seventy days. It was greatly aided by a previous knowledge of the region and by the earlier work of Schrader and Spencer, but the time available was too short to permit an excursion up Nizina River to determine the relation between the Triassic and the Paleozoic sediments on Skolai Creek, or to make a careful study of the Kennicott formation south of Young Creek. Both localities merit careful investigation because of the light they may throw on the stratigraphy of the region. The chapter in this report dealing with the Quaternary system was written by Mr. Capps, who also did the office work on the geologic map. The task of preparing the remainder of the description of general geology and of economic geology fell to the senior author.

CLIMATE.

The climate of Chitina Valley is pleasanter in many ways than that of the Pacific coast region of Alaska. Temperature variations are far greater, but the precipitation is less and the number of cloudy, disagreeable days is very much smaller. No continuous records of temperature and precipitation are at hand, and it is probable that none have been kept, although observations for parts of several years have been made at Kennicott and were made available through the kindness of Mr. Stephen Birch.

The Copper River region, of which Chitina Valley is a part, as has been stated previously, is separated from the Pacific coast by a broad belt of mountains nearly 50 miles across and ranging in height from 6,000 to 10,000 feet. This belt is broken only by the narrow canyon-like valley of the lower Copper River, and by its influence on the warm moisture-laden air of the Pacific it becomes an important factor in the climate of Copper and Chitina basins. Another factor of importance is the still loftier Wrangell group of mountains on the north.

The seasons of Copper River basin are a long winter and a short summer, separated by a still shorter spring and fall. Spring comes sooner in the upper Chitina Valley than in the Copper River valley proper, as is shown by the earlier breaking up of the ice. Snow goes from the valley bottoms by the middle of May and from the lower hills by the first of June, but enough remains on the mountain sides till the first or middle of July to hinder prospecting. The summer climate resembles that of some of our Northern States in late spring. Frosts are not expected from the middle of June to the middle of July, but by the first of September the snow line begins to descend on the mountain sides. After the spring break-up the volume of water in the streams, particularly those fed by snow fields and glaciers, gradually increases until it reaches a maximum about the middle of July; it then decreases rapidly as the cooler nights come on. The July period of high water is not the result of increased precipitation but of the warm weather and the bright sun on the snow fields. Cloudy days always make a very appreciable difference in the daily rise of the glacier streams. Sometimes, however, the rivers are flooded by unusually heavy rains and occasionally in winter by the breaking out of water confined in the glaciers. This took place in the Kennicott Glacier early in 1909. During a period of unusually cold weather the outlet of the subglacial stream known as the "pothole" was closed and the water backed up under the glacier till the pressure was so great that the ice could not resist it. The water burst forth from a new outlet and flooded the Kennicott and Chitina rivers, tearing up the ice and piling it in confusion. Fortunately no one was freighting on the river, and the new ice which formed afterward gave the best sledding ever known by freighters on the Chitina. A similar flood caused by the breaking out of confined waters from Nizina Glacier took place a few years previously. The high water of July makes the fording of Nizina River difficult and at times dangerous, but this difficulty decreases in August, and by the first of September it is ended. Temperatures low enough to allow standing water to freeze are usual in the latter part of August, and early in September the glaciers cease to be active and the streams are clear and low.

Temperatures of 30°, 40°, or even 50° below zero are experienced in winter, and the snowfall is heavy, although much less than on the coast.

Observations at Kennicott, at the mouth of National Creek, and at the Bonanza mine, a little more than 2½ miles away and 4,000 feet higher, showed that the temperature at the mine during the coldest weather was always considerably higher than at the lower camp.

The winter of 1908–9 was unusual because of its low temperatures and light snowfall. It resulted from these conditions that the streams were in places frozen to the bottom, and the water, breaking out above, ran down over the top and froze to a great thickness. Some of the so-called glaciers on Chititu Creek had a thickness of 15 or 20 feet and did not melt away till early in the following July, thus seriously interfering with placer mining. Such conditions are common enough in the streams of northern Alaska but are unusual in the Nizina district.

VEGETATION.

In this region, as in many other parts of Alaska, vegetation flourishes in a way that would be surprising to those who think of the country only as a region of continual cold and ice. The growing season is short, but the summer days are warm and much longer than in lower latitudes, so that in the few favorable weeks plants grow rapidly. Grass comes up as soon as the snow goes and by the first or middle of June there is good feed for horses in favorable places. It is not abundant in the lower valley bottoms, even in midsummer, and the best of it is found at or above timber line. There is good feed in the upper part of all the small valleys. A small leguminous plant, locally called " pea vine," grows on the gravel bars and in the fall and late summer makes excellent forage. It is nourishing, and horses are so fond of it that they will leave almost anything else to get it. Grass loses its nourishing qualities as soon as the frost strikes it, and for this reason miners and prospectors start their horses to the coast about the first of September.

All the lower mountain slopes of the Nizina district and all the valley bottoms except the flood plains of streams are covered with spruce timber. The upper limit of timber ranges from 2,500 to 4,000 feet above sea and is highest on the gentle and rounded slopes away from the glaciers, such as the south slope of the ridge west of Rex Creek and on Sourdough Hill. Timber suitable for lumber grows on the lower ground. The best of it is found on the flats south of Nizina River, from Dan Creek to Young Creek, in the drier ground at the base of the hill slopes. Some of the trees reach a diameter of 18 inches and are tall enough to furnish two 16-foot cuts. Besides the spruce, there are cottonwood and birch, but these have little value for lumber. A heavy growth of alders is usually found about timber line. Willows are present in the valleys, but are far less abundant in variety and amount than in northern Alaska. The "devilclub," so troublesome in the coast region, is found occasionally in the Nizina district also.

POPULATION.

During the early days of the Nizina gold excitement the white population of the district amounted to several hundred persons, but this number quickly decreased, as is usual in such stampedes. There are no accurate records of the number of early comers. Some of them were of the "hanger-on" class and stayed only long enough to learn that the district had little to offer them. The later population has been a variable one, but for the last two or three years it probably has not been far from 100. Most of this number were employed in the gold placers of Chititu and Dan creeks and the rest were prospecting for copper. With the completion of the railroad and the beginning of mining at Kennicott and the increased activity in the gold-producing streams that will come with better transportation the white population will increase. There is no permanent native population. Nizina River valley was the hunting ground of Chief Nikolai, and his house was near the mouth of Dan Creek, but since his death several years ago superstition has kept his followers from returning there until within the last two summers. The permanent dwellings of the Indians are on Copper River, where they spend most of the winter and where they fish in summer. It seems to have been the custom of many to leave the fishing ground only during the time of the fall hunting or in the trapping season.

TRANSPORTATION.

To provide satisfactory means and routes of transportation has been from the beginning the most serious difficulty the prospectors in Chitina Valley have had to meet. Up to the present time all supplies and equipment for the Nizina district have been brought from Valdez in winter by sled. The route usually followed in freighting is from Valdez to Tonsina over the Government trail, then by way of Tonsina, Copper, Chitina, and Nazina rivers to the destination. Occasionally, however, this route has been varied by crossing Marshall Pass at the head of Lowe River and following Tasnuna and Copper rivers to the mouth of the Chitina; but this latter route was given up because of the difficulties encountered on Tasnuna River and of the fact that the Government trail to Fairbanks is kept open all winter by the regular travel. The great advantage of the route lay in the ability to haul very heavy loads on the smooth ice of Copper River, thus saving time and horse feed, the two great items of expense, on this part of the trip. This route probably would have been used exclusively for freighting to Chitina Valley if a good trail down Tasnuna River had been available for travel.

The time consumed in carrying large outfits from Valdez to the Nizina district is from two to three months. The cost of freighting has varied from slightly less than 7 cents to 30 cents per pound, depending on the size of the outfit and the condition of the trail. The lower figure of cost is an exceptional one and is not possible under any other than the most favorable conditions. Probably about 10 cents per pound is an average cost for the larger companies when the trail is good.

Summer travel is over a route different from that followed in winter. The summer trail leaves the Government trail at Tonsina and crosses Copper River at the mouth of Tonsina River. From there it passes to the north side of Chitina Valley, entering the mountains by way of Kuskalana River and crossing Kuskalana and Fourth of July passes to Kennicott Glacier and River. No freighting is done on the summer trail, but the mail goes in over it twice each month.

Within the Nizina district trails connect the various camps and enable the miners to travel from one to another without serious difficulty, although there is little communication between them during the working season. The trails are all shown on the topographic map and need not be described in detail. The one most traveled is that over Sourdough Hill from McCarthy Creek to Chititu and Dan creeks. Because it is less swampy, it is used by many in preference to the lower trail around the west end of the hill, but the hill is steep and the climb is hard. One great difficulty with this trail is the necessity of fording Nizina River. A proposal to bridge the river at a point several miles below the present fording place will probably be carried out in the near future.

It is seen from the figures previously given that the cost of transportation is a heavy tax on all work done in the Nizina district. This expense has not only hindered copper prospecting but has delayed the installation of placer mining machinery also. This burden will be much lightened in a short time, however, for railroad communication with the coast is promised early in 1911. Construction work on the Copper River and Northwestern Railway was commenced under the present management at Cordova in 1908 and since that time has been pushed as rapidly as conditions permitted. In 1908 the tracks were advanced from Cordova to within 10 or 12 miles of Abercrombie Rapids, although the lower steel bridge over Copper River was not erected till the following spring. In 1909 the piers for a second bridge, at the river crossing between Childs

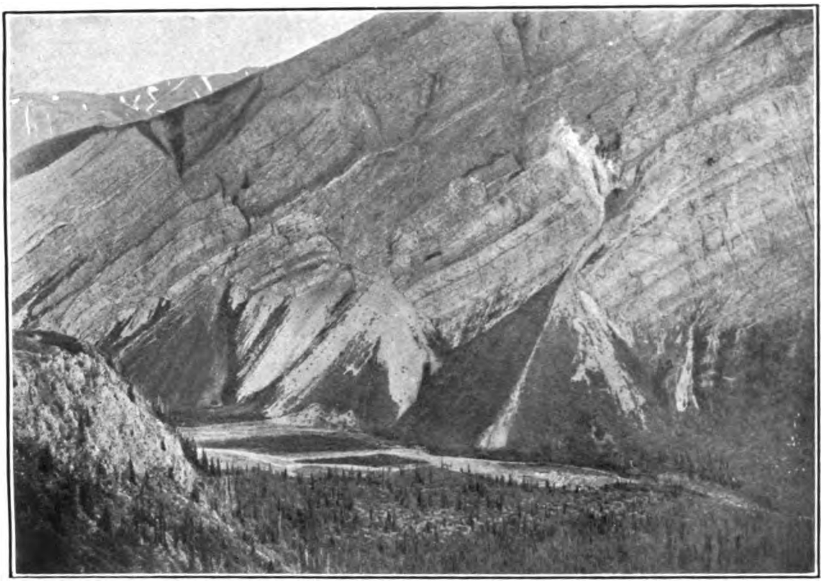
Glacier and Miles Glacier Lake, were built and the tracks were advanced to Tiekel River. With the completion of this part of the road most of the slow and difficult work was ended and there remained only 90 miles of track construction to reach Kennicott. This includes a third bridge over Copper River, between the mouths of Chitina and Kotsina rivers, where it is proposed to place a temporary pile bridge while the construction of piers for the permanent bridge is going on. The building of the railroad has not involved any unusually difficult construction problems for modern railroad engineering, and the greatest obstacles to operation will doubtless arise from weather conditions. Along Copper River the tracks are particularly exposed to obstruction by snowslides, and adequate provision for their protection will have to be made. Above Abercrombie Rapids the tracks follow the river bank on the débris-covered edge of Baird Glacier. The ice is overlain by a thin coating of loose rock and is overgrown with alders. It appears to have no motion, but it is probable that more or less melting goes on and that the tracks will require more attention and repair than in other places. Some have expressed uncertainty concerning the effect of the terrible winter winds that sweep down the lower part of Copper River valley and have even predicted that they would prevent the running of trains, but such difficulties have been overcome elsewhere and probably will be here. Railroad communication with the coast promises greater aid in the development of the Copper River valley than any other single enterprise yet undertaken.

TOPOGRAPHY.

RELIEF.

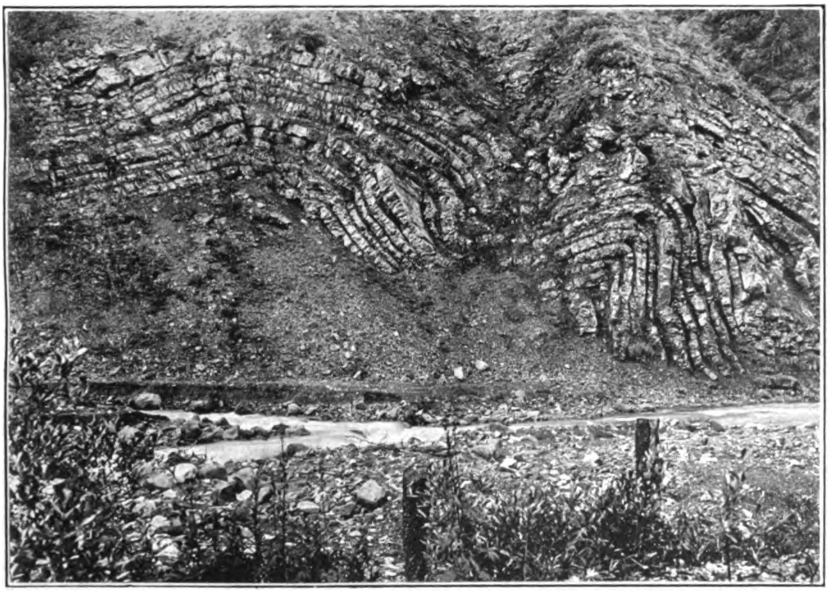
The Nizina district has been described as situated at the southeastern border of the Wrangell Mountains, in the region where this group merges into the Coast Range Mountains to the east and south. The mapped area does not extend far enough north or east to take in any of the larger snow fields or glaciers or to include the highest mountains of the Wrangell group or Coast Range, although peaks of 7,000 or 8,000 feet are shown. To the southeast is the broad lowland formed by the junction of Chitina and Nizina valleys. The map (Pl. II, in pocket) shows as the major features of relief two mountain areas separated by the valley of Nizina River, but other topographic forms are even as striking as these, particularly the steep, straight valley walls, the deep gulches tributary to Young Creek, and the peculiar wormlike rock glaciers.

Three geologic elements are involved in the relief—the high mountain masses, the gravel-covered lowlands, and the gravel benches or terraces. Glacial erosion and the character of the rock formation have



A. TALUS CONES ON EAST SIDE OF McCARTHY CREEK, AT BASE OF LIMESTONE CLIFFS.

See page 19.



B. FOLDED TRIASSIC LIMESTONE AND SHALE BEDS ON SOUTHWEST SIDE OF COPPER CREEK.

See page 28.

M 70 U

been strikingly effective in giving form to the mountains. The work of the ice in straightening and steepening valley walls is conspicuous on Chitistone River and the adjacent part of Nizina River and on the upper part of McCarthy Creek. It is also seen in the numerous cirque valleys in which most of the streams head. McCarthy Creek is a typical example of a glaciated valley in this district. Its upper part is a broad, open, U-shaped valley with gravel floor. Its lower part is a succession of rock canyons with high gravel terraces. These features, except the gravel terraces, are characteristic of every glaciated valley of the region and are probably the result of rapid head valley glacial erosion and the effort of the stream to establish a more advantageous grade after the melting of the ice.

Different kinds of rock were affected in different degrees by the glacial ice and by subsequent erosion. The massive Chitistone limestone forms precipitous cliffs and tall spires, as on Dan Creek, Chitistone and Nizina rivers, McCarthy Creek, and at Bonanza mine. The greenstone slopes are not so steep and are more uniform in surface contour; they rarely form perpendicular walls such as are common in the limestone exposures. The shales give smooth, rounded outlines where they have undergone glacial erosion and sharp, jagged peaks and ridges with steep, bare slopes where they have been subjected to attack by weather alone. These two features are seen in the shale area south of Dan Creek. Between Dan Creek and White Gulch the shale mountains are characterized by angular outlines and bare slopes, but south of Chititu Creek the same shales were overridden by the ice streams from Chitina Valley and present smooth, rounded contours. This feature, however, has been modified by intense postglacial erosion, with the production of such topographic forms as Blei Gulch and the deep gashes cut by tributaries of Young Creek. A different topographic form, dependent on the structure of the upper shale formation, is the flat top of the ridge on the west side of Nizina River directly opposite the mouth of the Chitistone. It is due to the almost horizontal position of the sandstone beds that form the base of the Kennicott in this locality.

Talus deposits cover the lowest mountain slopes and reach their greatest development at the bases of large porphyry exposures and limestone cliffs. In this connection it should be said that the occurrence of a small proportion of porphyry in talus slopes and rock glaciers is usually sufficient to obscure other kinds of rock. Talus fans of noticeable symmetry have been built up below gulches in the limestone formation east of McCarthy Creek (Pl. IV, *A*) and north of Chitistone River. The peculiar detrital accumulations here called rock glaciers are confined to the high mountainous parts of the district but are widely distributed in the mapped area. They are described in the discussion of Quaternary deposits.

The second important element in the relief of the district is the gravel-covered valley lowland areas. Their distribution is readily seen on the map. They represent the accumulated deposits of present glacial erosion and the reworked deposits of former glaciation, together with the contributions of present stream erosion. With the older bench gravels they occupy fully one-third of the mapped area. The bench gravels, which are of glaciofluvial origin, are most conspicuous about the mouth of Dan Creek, the lower parts of Chititu and Young creeks, and on McCarthy Creek, but are present in other places also.

DRAINAGE.

Nearly all the larger streams of the Nizina district originating within the mountain area head in glaciers, and those that do not thus head nevertheless receive much of their water from melting snow banks throughout all or part of the year. All the streams are swift and subject to rapid variations in quantity of water flowing in them. Nizina River falls 600 feet in 19 miles within the mapped area, or at the rate of 31.5 feet per mile. McCarthy Creek has a grade of 100 feet per mile and Chititu Creek 180 feet per mile in their lower courses.

In contrast with the well-drained mountain areas, the lowlands are swampy and dotted with numerous ponds and lakes. They are covered with an inferior growth of spruce and with moss that acts like a sponge to hold water and prevent its rapid run-off. The surplus water from the lakes is carried away in sluggish clear-water streams. These features are characteristic of the southwest part of the mapped area. Trails in such country are often almost impassable for horses in summer, and for that reason they keep to the gravel bars or the ridges.

DESCRIPTIVE GEOLOGY.

STRATIGRAPHY.

SEDIMENTARY ROCKS.

ROCK TYPES.

It has already been stated that the Nikolai greenstone is the oldest rock formation exposed in the Nizina district and that it is conformably overlain by the Chitistone limestone and a shale formation (McCarthy shale), both of which are of Triassic age. It was further stated that a great thickness of shale of Jurassic age—the Kennicott formation—rests unconformably upon the upturned edges of the greenstone, limestone, and shale; that these formations, particularly the Kennicott, were intruded by light-colored porphyritic igneous rocks; and that the most recent deposits of the district are unconsolidated gravels of Quaternary age.

The Nikolai greenstone, because of its relation to the Chitistone limestone, its importance as a geologic formation, and its structure, might fittingly be described in connection with the sedimentary formations. Inasmuch, however, as it is of igneous origin, its description will be taken up later in its proper place in the account of the igneous rocks.

TRIASSIC SYSTEM.

CHITISTONE LIMESTONE.

CHARACTER OF THE FORMATION.

The name Chitistone was applied by Rohn to the great Triassic limestone of the Nizina district because he found the limestone best developed along the Nizina in the vicinity of the mouth of Chitistone River. This name was later adopted by Schrader and Spencer and has since come into general use. The Chitistone limestone is a conspicuous formation occurring all along the south flanks of the Wrangell Mountains from Kotsina River to Dan Creek and probably extending into the valley of the upper Chitina. In the Nizina district the lower part of the Chitistone formation is made up of thick, massive beds of a dark-gray or bluish-gray color but weathering to a lighter gray on the surface. The upper part, on the other hand, is made up of thinner beds, and this thinness increases toward the top. A slight difference in chemical composition between the upper and the lower parts of the Chitistone limestone is indicated by the brownish-yellow weathering of the upper part. Changing conditions of sedimentation are indicated, too, in a more noticeable way by the appearance of thin shale beds at the top of the formation. This limestone is the oldest of the sedimentary formations exposed within the mapped area and lies on the Nikolai greenstone conformably, exactly as if both were sedimentary formations deposited in the same sea and the limestone had been laid down on the greenstone before any movement or disturbance had taken place in the greenstone. This conformable relation holds true wherever the contact has been examined, although in many places it is found that there has been movement of the two formations along this contact surface. In several places a bed of red and green shale with a maximum thickness of about 5 feet was found to intervene between the limestone and the greenstone, but it is not known whether the shale is widely distributed or not, since the limestone-greenstone contact is nearly everywhere covered with talus. The shale is present in the vicinity of Bonanza mine and on Kennicott Glacier.

Excellent sections of the Chitistone limestone are seen on the west side of Nizina River, opposite the mouth of Chitistone River, and on McCarthy Creek. On McCarthy Creek the lower part of the formation, which dips about 30° NE., consists of massive beds of bluish-gray limestone, making up approximately three-fifths of the total thickness. Above this lower massive portion is a succession of more thinly bedded limestone strata weathering a rusty-yellow color and making up the remaining two-fifths of the formation. The thickness of individual beds decreases from the base toward the top, as has been stated, and near the top thin beds of black shale make their appearance. Then comes an indefinite thickness, approximately 300 feet, of thin-bedded limestone and shale overlain in turn by a great thickness of black shale, which Rohn called the McCarthy Creek shale.[a] It is thus seen that there is a transition from the bedded limestones below through interbedded thin limestones and shales to shale above, and it is readily understood that difficulty arises in choosing a definite dividing plane between these two formations.

The section on Nizina River shows the same features as that on McCarthy Creek, but here the whole syncline is exposed, revealing the steep northward dip on the south, the horizontal bedding in the middle, and the gentle southward dip on the north. The bedding features are well shown in the center of the syncline for the whole succession from base to overlying shales. (See Pl. V.)

DISTRIBUTION.

The Chitistone limestone occupies a narrow band along the northeastern edge of the mapped area, extending southeastward from Kennicott Glacier (at the northern limit of the area) to the head of Copper Creek. The dip of the limestone along its southern boundary is to the northeast and decreases from approximately 30° in the vicinity of Kennicott Glacier and McCarthy Creek to only a few degrees on Dan and Copper creeks. It results from this that the width of the limestone belt is much less at the glacier and on McCarthy Creek than on Dan Creek. The limestone belt has a width of slightly more than 1 mile on the ridge between McCarthy Creek and East Fork, which is probably less than its width at any place between McCarthy Creek and Kennicott Glacier. East of Nizina River the limestone caps the mountains between Dan Creek and Chitistone River in the form of a broad, shallow syncline fully 5 miles wide. The continuity of limestone exposures is interrupted in many places by valley gravel and talus deposits, but aside from separate limestone areas produced in this way there are a number of small detached areas whose separation from the principal limestone masses represented on the map is due to other causes. Such an area is seen at the head of Nikolai Creek and owes its isolation to the fact that the overlying Kennicott formation has been only partly eroded. If all of the conglomerate and sandstone of the Kennicott

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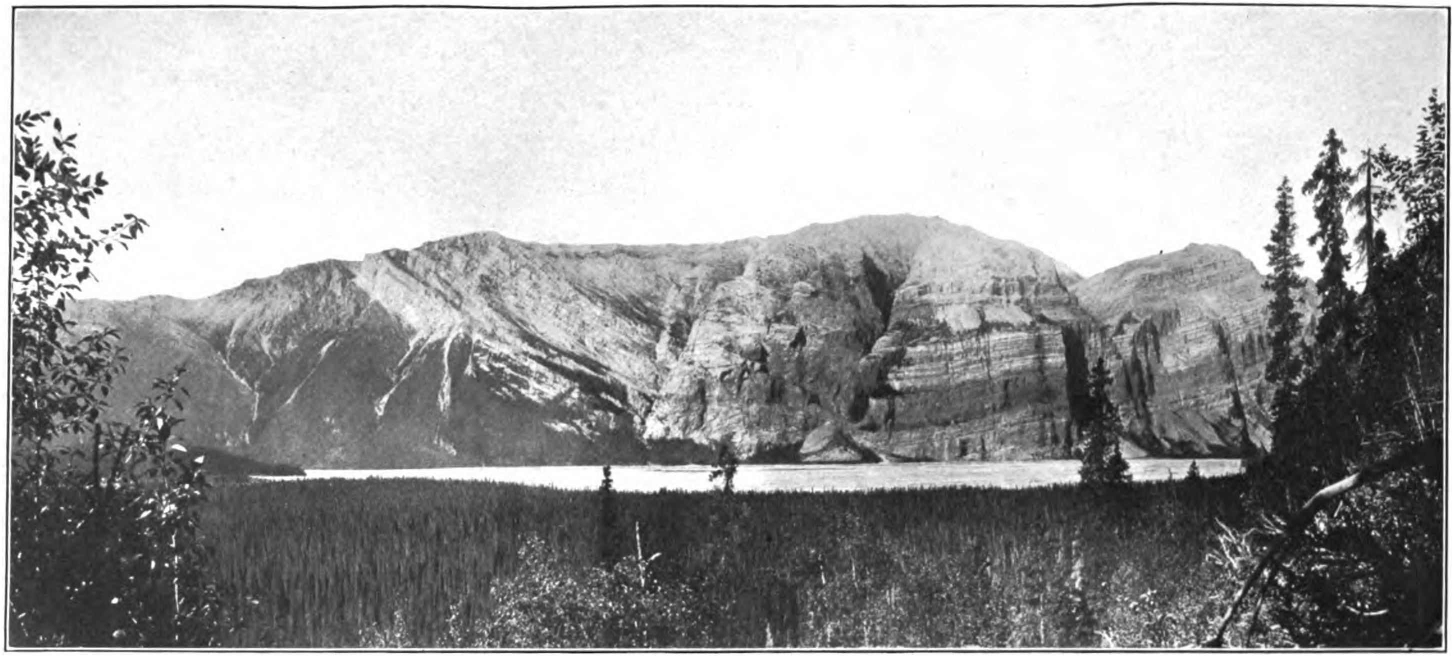
[a] Rohn, Oscar, A reconnaissance of the Chitina River and the Skolai Mountains, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 426.



LIMESTONE WALL ON WEST SIDE OF NIZINA RIVER NEAR MOUTH OF CHITISTONE RIVER.

The limestone overlies the Nikolai greenstone on the left. See page 22.

were removed, the small limestone area would be found to be part of the larger area to the east. Another isolated area lies south of Dan Creek, but in this case the limestone was separated from the main limestone mass to the north and reached its present position through faulting.

THICKNESS.

The two localities on Nizina River and McCarthy Creek afford favorable opportunities for measuring the thickness of the Chitistone limestone, since in both places the whole formation is present. One element of uncertainty presents itself, however—the difficulty of choosing the somewhat arbitrary plane to separate the limestone from the overlying shales; yet, since the intervening thin-bedded shale-limestone succession is probably less than 300 feet thick, the error in measurement, and the results are the same as on Nizina River. A 5 per cent, as will be seen later.

The base of the limestone in the central part of the syncline on Nizina River is hidden by river gravels, but since the curve of the beds is small and regular and greenstone is exposed along the base of the cliffs only a short distance north and south of the axis of the syncline, it is evident that almost the complete section of the limestone is shown in one vertical column. This section gives a thickness of 3,000 feet for the Chitistone limestone in its type locality. The McCarthy Creek section gives an almost equally good chance for measurement, and the results are the same as on Nizina River. A section north of Chitistone River gives a greater thickness than 3,000 feet, but as in this locality the limestone has been folded and faulted it is believed that the figures there are less reliable than those first given.

Exposures of Chitistone limestone extend westward to Kotsina River, less than 15 miles from Copper River, but the thickness is much less than in the Nizina district and in places is not more than 200 or 300 feet. No evidence has been collected to show that the limestone becomes progressively thinner from the east toward the west in Chitina Valley, and, although that may be the case, the decreased thickness in the valleys of Kotsina River and Elliott Creek may be due to erosion before deposition of the Kennicott formation took place.

AGE.

The age of the Chitistone limestone was long in doubt but is now known to be Upper Triassic. This age determination is based on fossil collections made in 1907 at a number of localities along the limestone area from Kotsina River to the Chitistone and on larger collections made in the Nizina district in 1909. All the collections were submitted to T. W. Stanton for determination and the forms present are contained in the following lists. These lists include, however, only the species collected within the area of the Nizina special map. The numbers given the specimens are the catalogue numbers in the National Museum. Concerning the collection of 1907 Dr. Stanton says in part:

> The collection is small and fragmentary, but it has proved sufficient to show quite conclusively that the beds in question are of Triassic age. The ammonites, especially, are all characteristic Triassic types, and the few brachiopods obtained are also Mesozoic. There is no indication of Paleozoic fossils in any part of the section represented. * * *
>
> The following lists give the form recognized from each locality. In most cases specific identifications have not been possible, but this does not lessen the accuracy of the age determination:
>
> Bonanza mine and Bonanza Creek:
> 4808; Nos. 9, 14 to 19, 21, 22—
> Undetermined corals.
> Terebratula sp.
> Spiriferina sp.
> Hinnites? sp.
> Pseudomonotis subcircularis (Gabb)?
>
> Jumbo Creek, near the Bonanza mine:
> 4809; Nos. 10 to 13, 20—
> Pentacrinus sp.
> Terebratula sp.
> Avicula? sp.
> Arcestes? sp.
>
> The last two named are certainly Triassic types of ammonites and probably belong to the genera to which they are provisionally assigned.
>
> South side of Chitistone River:
> 4810: Nos. 23, 24—
> Spiriferina? sp.
> Halobia sp.
> Arcestes? sp.
> Tropites? sp.
>
> The' last two are Triassic ammonites provisionally identified from imperfect specimens.

The list of fossils collected in 1909 is here arranged by localities. Dr. Stanton says of them:

> The fossils from the Chitistone confirm the recent determinations of that horizon and definitely prove that it is of Triassic age.
>
> Jumbo Creek:
> 6300—
> Base of Chitistone limestone corals? Too obscure for identification.
>
> McCarthy Creek:
> 6330—
> Terebratula sp. Probably Triassic.
>
> Nikolai Creek:
> 6303—
> Halobia sp.; related to H. superba Mojsisovics.
> Undetermined Pelecypod.
> 6306—
> Juvavites? sp.
> Arcestes sp.

Nikolai Creek—Continued.
- 6312—
  - Pseudomonotis subcircularis (Gabb).
  - Arcestes sp.
  - Juvavites? 2 sp.
  - Orthoceras sp.

Chitistone River:
- 6319—
  - Tropites sp.
  - (Lower part of Chitistone limestone.)
- 6320—
  - Halobia superba.
  - Arcestes.
- 6333—
  - Halobia superba Mojsisovics?
  - Arcestes sp.

Copper Creek:
- 6321—
  - Halobia superba Mojsisovics?

When Schrader and Spencer studied the geology of the Chitina Valley in 1900 they found no fossils in the Chitistone limestone and were unable to give conclusive evidence concerning the age of the limestone. They, however, correlated it with the massive Carboniferous limestone at the head of White River, first described by Hayes[a] and later by Brooks.[b]

This limestone is exposed on the north side of Skolai Creek, one of the eastern tributaries of Nizina River, and is conspicuous in Skolai Pass, between the heads of Skolai Creek and White River. The correlation of limestones so similar in appearance and so near to each other seemed to have much in its favor, but better opportunities for study have proved it to be incorrect.

Although the Chitistone limestone can not be correlated with the limestone on White River, it is known that limestone similar in appearance and of the same age as the Chitistone limestone is present on the north side of the Wrangell Mountains, in the depression between them and the Nutzotin Mountains. There is, however, no such development of Triassic limestone there as is seen in the Chitina Valley, and the known exposures are confined to one small area.

A table of correlations for the Mesozoic sedimentary rocks of Alaska is here given, from which it appears that Triassic rocks, so far as they are known at present, are confined to the region south of the Alaska Range. Aside from the Chitina region, Triassic rocks probably have their greatest development in the Cook Inlet region, where they occur principally in the form of cherts with a small proportion of shale and limestone beds.

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[a] Hayes, C. Willard, An expedition through the Yukon district: Nat. Geog. Mag., vol. 4, 1892, p. 140.

[b] Brooks, Alfred H., A reconnaissance from Pyramid Harbor to Eagle City, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 359.

Correlation of the Mesozoic sedimentary rocks of Alaska.

		Nizina district (Moffit and Capps, 1909).	Nabesna-White River district (Moffit and Knopf, 1908[a]).	Talkeetna and Matanuska district (Paige and Knopf, 1906[b]).	Cook Inlet and Alaska Peninsula (Stanton and Martin, 1904[c]).	Alaska Range (Brooks, 1902[d]).	Southeastern Alaska (Wright and Wright, 1908[e]).	Yukon Basin (Brooks and Kindle, 1908[f]).	Northern Alaska (F. C. Schrader, 1901[g])
Cretaceous.	Upper				Marine and non-marine shales and sandstones, conglomerates. coal. —Unconformity—			Conglomerates, sandstone, slate, and shale, cut by granite. —Unconformity—	Bergman series (?) Nanushuk series. Sandstones with some conglomerate, slate, and lignite. —Unconformity—
	Lower.			Limestone.			Shale, conglomerate limestone, graywacke and slate overlying andesitic lavas, tuffs, breccia, conglomerate, and sandstone, which in turn rest on granite intrusives.	Siliceous slate and quartzites, with some tuff and a little limestone, cut by basic dikes. —Unconformity—	Anaktuvuk series and Koyukuk series. Feldspathic sandstones and some conglomerate. Impure limestone, sandstone, slate, and igneous rocks. —Unconformity—
Jurassic.	Upper.	Kennicott formation. Conglomerate shale, sandstone. —Unconformity—	Banded slates, graywackes, and conglomerate, with some limestone and sandstone. —Unconformity—	Shales, sandstones, conglomerates, tuff, and arkose, with coal. —Unconformity—	Naknek formation. Conglomerate, arkose, sandstone, and shale, with interstratified andesite flows.				Corwin series. Gray sandstone, limestone and shale, quartzite, and some coal. —Unconformity—
	Middle.			Shales, sandstone, and conglomerate, with coal. Andesitic greenstone, tuffs, agglomerates and breccias, rhyolites, dacites, and tuffs.	Enochkin formation. Shales and sandstones, with some conglomerate beds.	Tordrillo group. Compact feldspathic sandstones and grits, slate, and some limestone.			

				Unconformity	Unconformity	Unconformity			
	Lower.				Tuffs and sandstones.				
					Unconformity				
Triassic.	Upper.	McCarthy shale, Chitistone limestone.	Limestone.		Thin bedded cherts, limestones, and shales usually much contorted and with many intrusive masses. Base not seen.	Skwentna group, age undetermined. Igneous rocks, with some slates and limestones.	Argillaceous limestones and calcareous sandstones.	Limestones and slates.	
						Unconformity			

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[a] Moffit, Fred H., and Knopf, Adolph, Mineral resources of the Nabesna-White district, Alaska: Bull. U. S. Geol. Survey No. 417, 1910, p. 16.

[b] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance of the Matanuska and Talkeetna basins, Alaska: Bull. U. S. Geol. Survey No. 327, 1907, p. 10.

[c] Stanton, T. W., and Martin, G. C., Mesozoic section on Cook Inlet and Alaska Peninsula: Bull. Geol. Soc. America, vol. 16, 1905, p. 410.

[d] Brooks, Alfred H., The Mount McKinley region, Alaska: Prof. Paper U. S. Geol. Survey No. 70, 1911, p. 591.

[e] Wright, F. E., and Wright, C. W., The Ketchikan and Wrangell mining districts, Alaska: Bull. U. S. Geol. Survey No. 347, 1908, p. 34.

[f] Brooks, Alfred H., and Kindle, E. M., Paleozoic and associated rocks of the upper Yukon, Alaska: Bull. Geol. Soc. America, vol. 19, 1908, p. 263.

[g] Schrader, F. C., A reconnaissance of northern Alaska: Prof. Paper U. S. Geol. Survey No. 20, 1904, p. 53.

McCARTHY SHALE.

CHARACTER OF THE FORMATION.

The term McCarthy Creek shale was used by Rohn to designate the black shales immediately overlying the Chitistone limestone, and the formation was described by him as "a series of soft, black, highly fissile shales and slates."[a]

The formation as it is exposed in the Nizina district is essentially a shale formation, although at its base are numerous thin limestone beds forming part of the transition zone at the top of the Chitistone limestone or the base of the shale. Thin beds of limestone are found interstratified with the shales wherever they are exposed within the mapped area, but are not abundant and form only a small proportion of the whole. The top of the McCarthy shale has not been recognized. Bedding is easily distinguished in most places either by the presence of the thin limestones or of thin limy shale beds with surfaces highly colored by weathering. Some of the smooth bare hilltops about the eastern tributaries of East Fork are marked with exceedingly intricate patterns produced by the colored beds, for the McCarthy shale is found to be intensely folded wherever it has been examined, and if the folds are cut by planes or curved surfaces making slight angles with their axes the patterns appear.

The folding in the McCarthy shale strongly contrasts with both that of the Chitistone limestone and that of the Kennicott formation. Pronounced folding took place in the upper thin-bedded part of the limestone in a few localities. It begins to be conspicuous in the transition beds at the base of the shale (see Pl. IV, *B*, p. 18) but was never found in the massive beds at the base of the limestone. The limestone beds were more able than the shale to withstand the pressure that tended to deform them, and that ability increased as the thickness of the beds increased. Another factor of strength lay in the massive flows of the Nikolai greenstone, which lent its support to the heavy beds of the limestone in resisting deformation.

DISTRIBUTION.

The principal area of McCarthy shale represented on the geologic map (Pl. III, in pocket) lies between McCarthy Creek and Nizina River, at the north edge of the sheet. This, according to Rohn, is the south edge of a succession of shales extending north in the McCarthy Creek valley for a distance of 6 or 8 miles and constituting the type locality for the formation. This is not only the largest area of the shales examined but it also shows a greater thickness than any other area, for it suffered less from erosion before the Kennicott formation was deposited.

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[a] Rohn, Oscar, A reconnaissance of the Chitina River and the Skolai Mountains, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 426.

The McCarthy shale and the shale-limestone transition zone below it form the base of the mountains south of Copper Creek. The formation is separated from the overlying Kennicott formation by a distinct unconformity, but the black shales of the two formations are so similar in appearance that they were not distinguished until the detailed work of 1909 was undertaken. Only the base of the McCarthy shale is exposed on Copper Creek. The upper part was removed by erosion before deposition of the Kennicott began. A smaller area of the Triassic shale forms the mountain top north of Texas Creek, and the formation is present in other places overlying the limestone north of Dan Creek but does not fall within the boundaries of the mapped area.

THICKNESS.

Accurate measurements of the thickness of the McCarthy shale were not obtained, because it is probable that only a part of the total thickness is exposed within the mapped area. It is possible, moreover, that the complete original section is no longer represented in this district, for a long erosion interval intervened between the deposition of the Triassic shales and the Jurassic shales. During this interval much of the Triassic sedimentary formations and of the Nikolai greenstone was removed. Another factor of uncertainty besides the amount of the shales that have been removed by erosion is the thickening and reduplication of beds that arise from folding and faulting. It is probable, however, that the McCarthy shale has a thickness nearly as great as the Chitistone limestone; possibly it is greater.

A thickness of about 1,500 feet of Triassic shale overlies the limestone on the west side of Nizina River. The shales near the center of the broad syncline in this locality have a horizontal position and are probably less distorted by folding than they are to the northwest. This measurement is considered the minimum and probably much less than the true thickness, for some of the shale has certainly been removed by erosion..

The mountains about the head of the East Fork of McCarthy Creek are made up of the black Triassic shales. They reach an altitude of 6,960 feet above sea level or 3,000 feet above the limestone shale boundary at the creek on the southwest. The shales are much folded about the upper part of the East Fork valley, and measurements are consequently uncertain, but it is probable that the thickness of the formation is at least 2,500 feet in this vicinity. No measurements of value were obtained in the Copper Creek section, for, as previously stated, only a part of the formation is present there.

It is evident from what has been said that the total thickness of Triassic sediments in the Nizina district is great and that it is probably not less than 6,000 feet. One-half of this figure represents a limestone whose thickness can be stated with a considerable degree of accuracy; the remainder represents a great shale formation whose thickness is stated only approximately.

AGE.

The McCarthy shale is of Upper Triassic age. Some of the beds are abundantly fossiliferous, especially those near the base of the formation and in the transition zone below, and fossils can usually be found in the higher parts of the formation if search is made for them. Shells of *Pseudomonotis subcircularis* (Gabb) are so plentiful in some of the shale beds between the thin limestones that the rock can not be broken without showing them; they appear, however, to be almost the only forms represented.

A list of fossil localities follows; the determinations are by T. W. Stanton.

McCarthy Creek:
  6314—
    Pseudomonotis subcircularis (Gabb).
Nikolai Creek:
  6311—
    Two or more undetermined ammonite genera represented by fragmentary specimens.
Dan Creek:
  6317—
    Pseudomonotis subcircularis (Gabb).
Copper Creek (two localities):
  6323—
    Pseudomonotis subcircularis (Gabb).
  6335—
    Pseudomonotis subcircularis (Gabb).

Areas of Triassic shale are scattered along the south slope of the Wrangell Mountains as far west as the Kuskulana and probably as far as the Kotsina also, but in the earlier work in this region the Triassic shales and the black Jurassic shales were not separated because the presence of an immense thickness of Jurassic shales in this valley was not known at that time. It is now certain that a considerable part of the shale areas of Chitina Valley formerly considered to be Triassic are in reality of Jurassic age.

No Triassic shale corresponding in thickness or other characters to the McCarthy shale is known in Alaska. Other regions of Triassic sediments of similar age have been pointed out (see correlation table, pp. 26-27), but the conditions under which they were deposited were different from those in the Nizina district, and although they may be in part contemporaneous the resulting formations are distinct.

JURASSIC SYSTEM.

KENNICOTT FORMATION.

CHARACTER OF THE FORMATION.

The name Kennicott was adopted by Rohn to designate the conglomerate and sandstone succession which he found resting unconformably on the Triassic shales of McCarthy Creek and correlated on fossil evidence with the light-colored arkoses, shales, and limestones between Lachina River and Kennicott Glacier. Rohn did not recognize the black shale south of Nikolai Creek as part of his Kennicott formation, but within the district under consideration the black shale is far more important in amount than the basal conglomerate and sandstone members.

The Kennicott formation as the term is here used consists largely of black shale, but it includes conglomerate, grit, sandstone, and impure limestone members and is intruded by great masses of light-colored porphyritic rock. It is the youngest of the consolidated sedimentary deposits represented on the geologic map (Pl. III, in pocket) and is more widely distributed within the mapped area than any of the formations previously described. One of the characteristics of the Kennicott is its variation in appearance and composition at different localities. This statement is more applicable to its basal than to its upper part and refers to features that resulted from changing shore conditions of sedimentation. These differences will be brought out by a description of the Jurassic rocks northwest of Nizina River, where the basal part is better represented, and southeast of Nizina River, where the middle and upper parts are better represented.

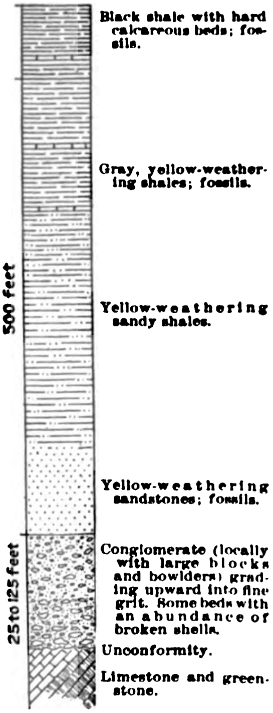
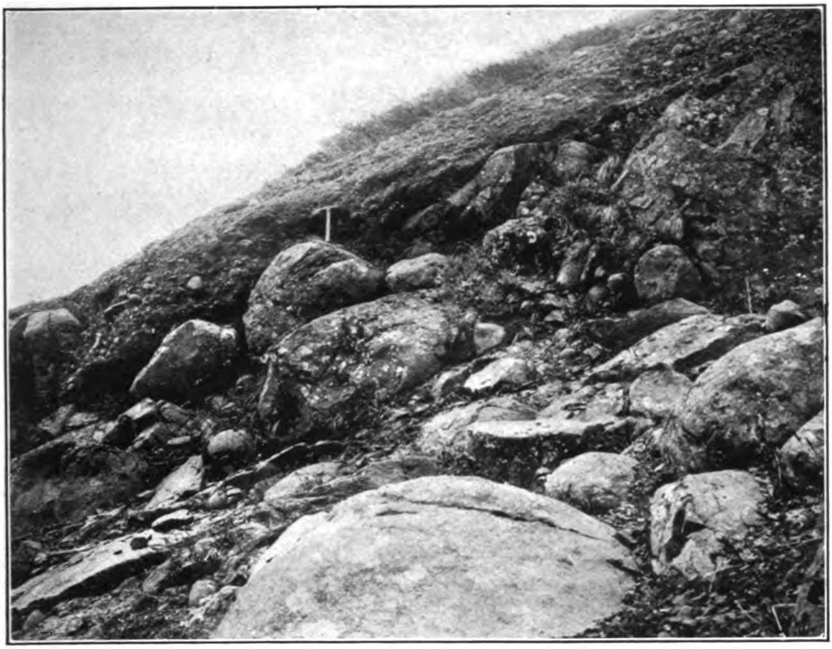

Black shale with hard calcareous beds; fossils.
Gray, yellow-weathering shales; fossils.
500 feet
Yellow-weathering sandy shales.
Yellow-weathering sandstones; fossils.
Conglomerate (locally with large blocks and bowlders) grading upward into fine grit. Some beds with an abundance of broken shells.
25 to 125 feet
Unconformity.
Limestone and greenstone.

FIGURE 2.—Columnar section of the basal part of the Kennicott formation exposed on Nikolai Creek.

The Kennicott formation where it is exposed about the head of Nikolai Creek may be subdivided into three members as follows: A basal member made up of conglomerate and sandstone; a second member consisting chiefly of light-gray, yellow-weathering shale; and an upper member of dark-gray or black shale interstratified with occasional beds of impure limestone or hard calcareous shale (fig. 2). The basal member shows notable differences in lithologic character and thickness as it is followed from one outcrop to another.

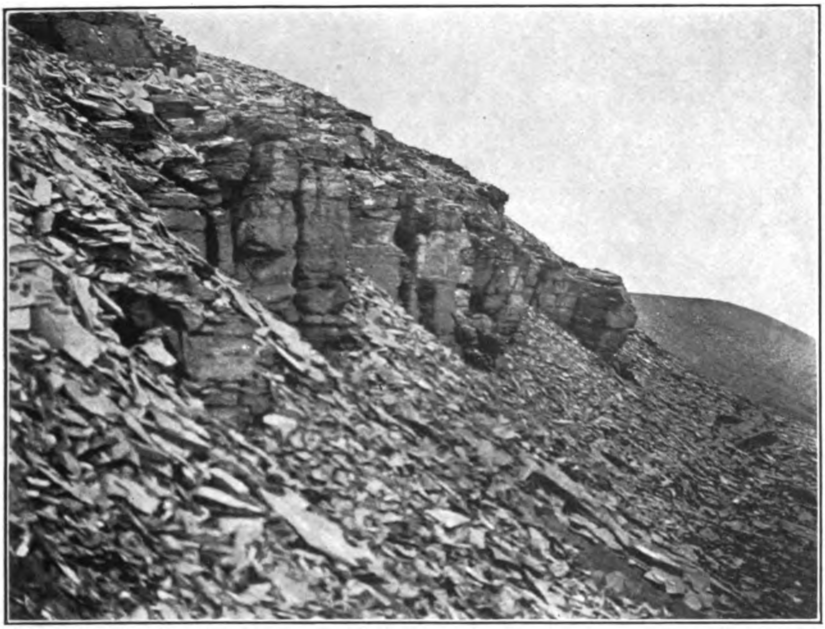
These differences, except in thickness, are dependent in large measure on the kind of rock immediately underlying the Kennicott. In nearly all places the lowest beds of the formation consist of conglomerate, but this conglomerate presents a different appearance in almost every exposure, for there is nearly every gradation between an even-grained grit whose well-worn pebbles are of uniform size and no larger than grains of wheat to a coarse agglomerate with blocks and bowlders up to 8 or 10 feet in diameter (Pl. VI, *A*). Such coarse material has probably traveled but a short distance from its source and may represent a shore-line cliff. It is not a constant feature of the basal Kennicott and its exposures are not extensive, for the very large bowlders are found in only a few localities. In many places it was noticed that most of the pebbles in the conglomerate are of the same material as the older beds on which the conglomerate rests—that is, where conglomerate overlies greenstone most of the pebbles are greenstone and where it rests on the Triassic shale most of the pebbles are shale. Limestone pebbles are not so numerous as pebbles of greenstone and shale, yet conglomerate of this formation containing a large proportion of rounded limestone fragments is found in other parts of the Chitina Valley. Some of the conglomerate contains a considerable number of diorite and porphyry pebbles, but it was not found in place in the vicinity of Nikolai Creek, where the basal conglomerate of the Kennicott is best developed within the area mapped. Nearly all of the fragments are well rounded and waterworn, and it is only in the very coarse conglomerate that angular outlines are noticeable. Even in such places the edges and corners of the blocks are usually worn away.

The filling between pebbles is finely ground material from the same source as the pebbles and is for the most part a greenish sandstone or graywacke. The average size of fragments composing the basal member of the formation decreases rapidly as distance from the base increases, until the conglomerate gives way to sandstone. In most localities about Nikolai Creek where exposures occur it is found that the upper half or three-fourths of the basal member consists of fine greenish sandstone or graywacke containing little quartz and seemingly derived largely from the Triassic shale and the greenstone. This upper part shows far less variation in character than the conglomerate, although in the base thin beds of graywacke alternate with thin beds of conglomerate. There are places where the fine conglomerate and graywacke contain considerable lime and become practically an impure limestone, but such beds are not persistent. Some of them consist in part of broken shells, yet it is difficult to find determinable fossils among them and still more difficult to secure the fossils when found, since they are in most cases partly decomposed and fragile.



A. BOWLDERS IN CONGLOMERATE AT BASE OF KENNICOTT FORMATION ON SOUTH BRANCH OF NIKOLAI CREEK.

See page 32.



B. SANDSTONE OF KENNICOTT FORMATION ON RIDGE SOUTH OF NIKOLAI MINE.

See page 33.

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This lowest conglomerate-sandstone member of the Kennicott formation on Nikolai Creek has a thickness ranging from 25 to 125 feet, the greater part of which is graywacke, the remainder conglomerate or grit. In a few places the basal member appears to be entirely absent, although because of faulting and talus slopes its seeming absence may be explained in other ways. Furthermore, its persistence as a whole in many other places in spite of rapid changes in character and of variation in thickness makes it probable that if it is not seen in a particular locality the failure to find it is due to one of the causes mentioned.

The middle member of the formation on Nikolai Creek shows far less variation in character than the lower one, but it does not appear so conspicuously in other parts of the Nizina region. It consists of shale and shaly sandstone, but shale predominates. The sandy phases are more or less local, and the best exposures are on the ridge south of Nikolai mine (Pl. VI, *B*). A freshly broken surface of the shale shows a fine-grained rock of light color, but both shale and sandstone weather a bright yellow that makes them conspicuous wherever they are exposed. Both shale and sandstone break down into thin fragments under the influence of the weather, and the débris from their ledges give rise to prominent talus slopes. Occasionally fossils are found in the sandstone, and rarely a shell is seen in the shale, but fossils are not abundant and it requires some search to find any of value. The thickness of the yellow-weathering shales is as great as 500 feet in the mountain between Nikolai Creek and the East Fork of McCarthy Creek. At the head of Nikolai Creek 375 feet of yellow-weathering shale overlies the conglomerate, but some of the shale has been eroded away.

The highest member of the Kennicott in the Nikolai Creek vicinity consists of black shale, with interstratified hard, impure limestone and calcareous shale beds ranging in thickness from 1 inch to 2 feet. The hard beds form only a small proportion of the total thickness, probably less than one-tenth, but although jointed and broken they stand out in relief from the softer, crumbling black shales and form a conspicuous part of the whole. This black shale resembles closely the black shales of the Triassic. The hard beds assume a rusty-yellowish color on weathering, just as in the Triassic shales, and there seems to be no way, except by their stratigraphic position and their fossils, to distinguish them from the older shales. Fossils are fairly plentiful in some beds of this member, especially those in the hard beds, and are in a better state of preservation than those found lower in the formation.

From 125 to 150 feet of these shales are exposed north of Nikolai Creek, but the figures take no account of what has been removed by erosion or what has been caught up into the intruded porphyry.

Locally erosion has destroyed the upper member, leaving the basal and middle members. In some localities both the middle and the upper members have been removed, and without doubt the Kennicott was once present in large areas where no trace of it is now found.

The section of the Kennicott formation exposed on Dan Creek is many times thicker than the section that has been described. The Nikolai section represents a phase of the basal Kennicott that is thought to correspond more fully with the Kennicott observed west of Kennicott Glacier and still farther west in the Chitina Valley than does the Dan Creek section. An excellent exposure of the base of the Kennicott formation was found on Eagle Creek, in the Copper Creek valley. All the upper part of the long ridge separating Eagle Creek from Copper Creek is made up of lower Kennicott beds. They rest on the edges of thin limestone and shale beds that belong to the transition zone between Chitistone limestone and McCarthy shale. The limestone and shale beds have a dip about 20° greater than the overlying Kennicott, and the unconformity is shown in diagrammatic clearness. The basal beds of the Kennicott at this place consist of from 150 to 200 feet of fine conglomerate or grit overlain by sandstone. Black shale overlies the sandstone and forms the top of the ridge extending southeast to the main mountain mass. This basal grit was traced northwest in Copper Creek valley to the vicinity of the limestone area north of Idaho Gulch. It may be regarded as a constant feature of the Kennicott in the Nizina district. In most places it is somewhat fossiliferous. Pyramid Peak, at the head of Copper Creek, appears to be made up entirely of rocks belonging to the Kennicott formation. The lower part is black shale, but the top shows bedding lines that are thought to represent sandstones and impure limestones. Sandy shales and hard sandstones are interstratified with the black shales on Rex Creek, and the tops of the mountains between Rex Creek and White Creek contain a large amount of gray sandstone and impure limestone. Beds of brown-weathering nodular limestone in the shales high up on the slopes of these mountains contain ammonite shells 15 or 18 inches across. These mountains appear to be at the axis of a broad shallow syncline and give good sections of the formation.

A feature of geologic interest is presented by the sandstone dikes that cut the black shales east of Rex Creek. These dikes range in thickness from a fraction of an inch to 5 or 6 inches and cut the shales just as an igneous dike would. They are composed of angular fragments of quartz, feldspar, biotite, calcite, and pyrite mingled with fragments of shale. They are composed of the same material as some of the associated sandstone beds and are numerous in places.

Bedding in the black shales of Blei Gulch, on the south side of Chititu Creek, is shown by lines of small limestone concretions and thin discontinuous calcareous beds. More than 4,500 feet of black shale dipping low to the southwest is exposed in Blei Gulch. Young Creek, south of Chititu Creek, flows in a shallow canyon whose walls are composed of black shale of the Kennicott formation. This shale forms the lower slopes of the ridge south of Young Creek, and it is probable that Kennicott sediments make up most of the ridge. The ridge was not examined in detail owing to lack of time, but a section up the first southern tributary of Young Creek east of Calamity Gulch shows rocks of the Kennicott formation. The section extends up the east branch of this creek. For a distance of nearly three-fourths of a mile from its mouth the creek flows over black shales with occasional limestone beds, all dipping southwest at angles of 30° or less. Thence for nearly a fourth of a mile are rocks that have been crumpled and much faulted. They consist of shales with interbedded calcareous shales and limestone, from which fossils were collected. In many places the strata of this disturbed zone stand on edge, and it is evident that displacements of importance have taken place. A peculiar feature of this locality is seen in the limestone nodules, which occur in beds and reach diameters of 2 or 3 feet. They consist of bluish-gray limestone and show parallel bedding lines crossing them. They were seen at a number of places on Young Creek. South of this faulted zone the creek flows for another three-fourths of a mile over black shales and thin gray and brown sandstones. The shale predominates but the sandstones form an important part of the whole. The dip of these shales and sandstones is steeper than is usual in the Kennicott formation of the Nizina district, ranging from 30° to 50°. A massive conglomerate succeeds the shale and limestone on the south at a point 1,500 feet above Young Creek. The conglomerate is several hundred feet thick and is made up of well-rounded pebbles loosely cemented together, many of which are 5 or 6 inches in diameter. It appears to have been deposited conformably on the underlying shale-sandstone beds, but there is reason to believe that movement has taken place along the contact at this locality. No proof was secured to show that this great conglomerate does not mark an unconformity in the Kennicott formation or between the Kennicott and a succeeding formation, but the relation appears to be one of conformity in other places west of this creek where the contact was examined. Flat-topped or mesa-like hills composed of conglomerate beds dipping low to the south are scattered along the top of this ridge both to the east and to the west of this section. According to Schrader's field notes of 1900, the conglomerate on the west end of the ridge south of Young Creek is interstratified with a few beds of arkose sandstone and probably does not exceed 500 feet in thickness. It contains granite bowlders up to 9 inches in diameter, dark limestone, flint, quartz, gray slate and grit, and green gneissic rock, but

Schrader did not find any pebbles of Nikolai greenstone. The arkose or sandstone underlying the conglomerate was measured by Schrader in a very favorable section, where the dip was low to the south-southeast, and was found to be between 2,000 and 2,500 feet in thickness.

There is no reason to doubt that this succession of shales, limestones, sandstones, and conglomerate found in the ridge south of Young Creek corresponds to the bedded rocks seen in the high mountains at the head of Copper, Rex, and White creeks. It therefore represents the upper part of the Kennicott formation as it is known at present.

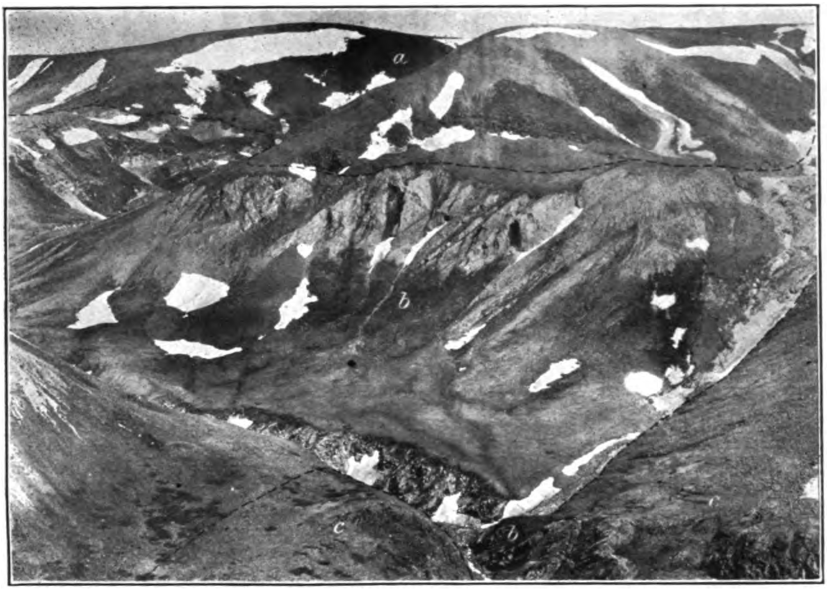
The unconformable relation of the Kennicott formation to the older sedimentary rocks and the Nikolai greenstone is plainly seen in both the localities whose sections have been described and is shown in the view (Pl. VII, *A* and *B*) taken at the head of Nikolai Creek. Kennicott sediments there rest on the upturned and truncated beds of the Nikolai greenstone, the Chitistone limestone, and the McCarthy shale. The dip of the younger beds is low in most places, ranging from 10° to 20° W. or SW. On the other hand, the dip of the underlying sediments and the lava flows (Nikolai greenstone) are considerably greater and in a different direction, averaging about 30° or 35° NE.

One feature of the Jurassic sediments that is more noticeable on White and Young creeks than in other parts of the district is the rapidity with which they break down under the action of weathering. Such topographic forms as Blei Gulch and the gulches tributary to Young Creek are due to this cause. Blei Gulch in particular shows how readily the shales are attacked and how little they are able to resist the attacks as compared with the greenstone and limestone. The soft shale débris accumulates faster than the water can carry it away and the mouth of the gulch is choked with it.

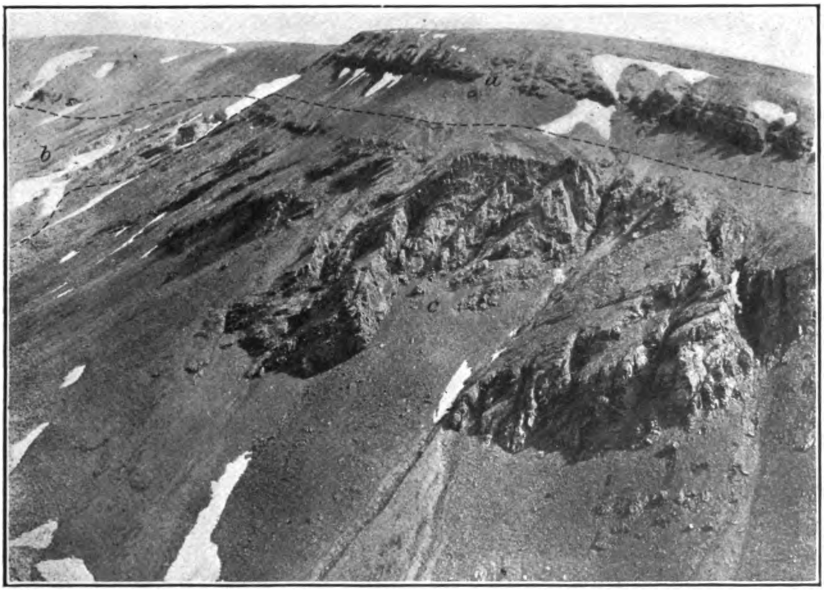
The Kennicott was deposited on an old submerged land surface. In a broad way this surface on which the Kennicott formation of Nikolai Creek lies was flat, but it is readily seen on examining the contact that there were minor irregularities in it such as are present in any level country. The conglomerate and graywacke beds of the basal Kennicott sag down into hollows of the underlying surface, and at one locality pebbles and sand were seen filling old cracks in the Chitistone limestone.

DISTRIBUTION.

The Kennicott formation occupies probably three-fourths of the total area represented on the geologic map (Pl. III, in pocket), for if a line be drawn from the mouth of National Creek to Pyramid Peak practically all of the consolidated deposits south of it are Kennicott. It forms the high angular mountains between Dan and Chititu



A.



B.

UNCONFORMITY BETWEEN TRIASSIC AND JURASSIC FORMATIONS AT HEAD OF NIKOLAI CREEK.

a, Sandstone and shale of Kennicott formation; *b*, Chitistone limestone; *c*, Nikolai greenstone. The two views placed side by side would form a panorama. See page 36.

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creeks and makes up the principal part of Porphyry and Sourdough peaks, although its presence is so obscured by porphyry intrusions in these two last-mentioned mountains that its amount is apt to be underestimated. It doubtless underlies also the gravel deposits of the lowland south of Nizina River.

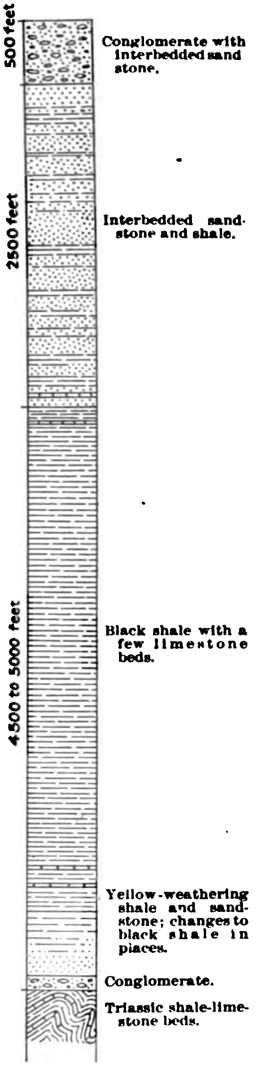
500 feet
Conglomerate with interbedded sandstone.
2500 feet
Interbedded sandstone and shale.
4500 to 5000 feet
Black shale with a few limestone beds.
Yellow-weathering shale and sandstone; changes to black shale in places.
Conglomerate.
Triassic shale-limestone beds.

FIGURE 3.—Generalized columnar section of the Jurassic sediments in the Nizina district.

Without question Jurassic sediments are far more widespread in Chititu Valley than was suspected before the field work of 1909 was undertaken. They extend eastward beyond the Nizina district into the upper valley of the Chitina and westward along the flanks of the Wrangell Mountains, where it is certain that they have not been fully differentiated from the Triassic shales, just as was true in the Nizina district. The separation of Jurassic from Triassic shales will require more detailed field work than has yet been given them.

THICKNESS.

No such favorable section was found for measuring the thickness of the Kennicott formation as that furnished by the walls of Nizina River for measuring the Chitistone limestone, and the figures given are secured from a study of a number of sections at different localities (fig. 3). The total thickness given should be regarded as having only approximate accuracy.

The coarse fragmental beds, including conglomerate and grit at the base of the Kennicott, range in thickness from 25 to 150 or 200 feet. An intermediate figure of 100 to 150 feet is believed to represent a fair estimate for the thickness of these beds throughout the district. It seems proper to include the yellow-weathering shales and sandstones of Nikolai Creek with the black shales, since they are a local feature and contemporaneous in time of deposition with the lower part of the black shale south of Nizina River. On this basis the black shale member at the heads of Copper and Rex creeks has a minimum thickness of not less than 4,500 feet, yet the black shales of Williams Peak south of Dan Creek suggest a considerably greater thickness, possibly as much as 6,000 feet. This measurement includes all beds from the top of the conglomerate and grit to the beginning of the interbedded shale-sandstone succession that forms the tops of the high mountains at the heads of Copper and Rex creeks and the upper part of the ridge south of Dan Creek. The shale-sandstone member has a thickness of about 2,500 feet. If, now, 500 feet, representing the heavy conglomerate of Young Creek, be added to the measurements already given, a minimum thickness of over 7,500 feet is obtained for the Kennicott formation in the Nizina district.

AGE AND CORRELATION.

Fossils have been collected from all parts of the Kennicott formation, but unfortunately the stratigraphic range of the forms is so great that they do not fix its age definitely. It appears most probable that the Kennicott formation was laid down in Upper Jurassic time, but there is a possibility of its being Lower Cretaceous. The probability of its Jurassic age rests in considerable measure on the presence of a species of *Aucella* collected first by Rohn and later by Schrader and Spencer and identified by T. W. Stanton. Schrader and Spencer collected fossils at other localities as well as in the Nizina district, and on the evidence of these fossils the formation was referred to "the doubtful series lying at the top of the Jurassic or at the base of the Cretaceous."[a]

The list of fossils follows.

Inoceramus eximius Eichwald?
Belemnites sp.
Halobia occidentalis Whiteaves?
Rhynchonella sp.
Pecten sp.
Avicula sp.
Aucella pallasi Keyserling?
Lytoceras sp.
Hoplites sp.
Olcostephanus? sp.
Gryphæa sp.
Sagenopteris sp.

Concerning *Inoceramus eximius* Dr. Stanton says:[a]

> This form is represented by a single specimen collected on Chitty Creek. It may be distinct from Eichwald's species originally described from Turkusitun Bay, in Cook Inlet, and referred by him to the Neocomian. Eichwald described three other species—*I. ambiguus*, *I. porrectus*, and *I. lucifer*—all belonging to one section of *Inoceramus* from the same horizon in Alaska. The present shell does not agree perfectly with any of the figures, but it is most nearly like *I. eximius* and probably comes from the same formation. Similar forms occur both in the Jurassic and in the Cretaceous, but the evidence of the other fossils from this part of Alaska favors the reference of the Kennicott formation to the Jurassic.

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[a] Schrader, F. C., and Spencer, A. C., The geology and mineral resources of a portion of the Copper River district, Alaska: Special publication of the U. S. Geol. Survey, 1901, p. 50.

Of the form referred with a question to *Halobia occidentalis* Dr. Stanton says:

> The specimens agree fairly well in sculpture and general appearance with some of the figures of Whiteaves's species from the Liard River and may be identical with it. They are, however, somewhat suggestive of *Hinnites linænsis*, from the Jurassic(?) of Siberia.
>
> *Sagenopteris* is a genus which occurs both in the Jurassic and in the Cretaceous, but the species is thought by Prof. Ward, to whom it was shown, to be near a species occurring in the Jurassic of the Pacific coast.

Concerning the general relations of the fossils from the Kennicott formation Dr. Stanton observes:

> These fossils are all either Upper Jurassic or Cretaceous, with a suggestion of a somewhat younger age for a few localities. In the present state of knowledge and with these small collections it is not practicable to determine whether they represent one horizon or several. In my opinion, they probably all belong to the Upper Jurassic, though subsequent work may show the contrary. The question is connected with the still unsolved problem of the exact boundary between the Jurassic and the Cretaceous in the *Aucella*-bearing beds of Russia, Siberia, and the Pacific coast region of North America. The *Aucella* occurring in the Copper River district appears to be referable to a Russian Jurassic species, but it is also quite similar to the Cretaceous form in the lower Knoxville beds of California. The few other forms are mostly undescribed species of types that occur both in the Jurassic and in the Lower Cretaceous.

A single fossil collected on Chititu Creek in 1907 was referred to Dr. Stanton and described by him thus:

Chititu Creek:
- 4811; No. 26—
  - Perisphinctes, sp. This ammonite is not a typical Perisphinctes, but it is probably of Jurassic age, certainly not older than Jurassic.

The much larger collection made in 1909 was also referred to Dr. Stanton, who says of them: "The fossils from the Kennicott indicate that one fauna ranges throughout the formation and that its age is most probably Jurassic, though the types represented in the collection are not as definite as could be wished for determining between Jurassic and Cretaceous. The entire absence of *Aucella* is noteworthy in view of the fact that that genus has previously been reported from the formation." The list of fossils arranged by localities and with the catalogue numbers of the National Museum follows.

McCarthy Creek:
- 6301—
  - Inoceramus sp.
- 6313—
  - Lytoceras sp.
  - Phylloceras sp.
    - Base of Kennicott.

Nikolai Creek:
  6302—
    Inoceramus sp.
      Base of Kennicott.
  6304—
    Rhynchonella sp.
    Pecten sp.
      Base of Kennicott.
  6305—
    Rhynchonella sp.
    Terebratella? sp.
    Exogyra sp.
    Pecten sp.
      Collected near 6304.
  6307—
    Phylloceras sp.
  6308—
    Inoceramus sp.
      Lower part of Kennicott formation.
  6309—
    Rhynchonella sp.
    Inoceramus sp.
  6310—
    Rhynchonella sp.
    Terebratella? sp.
      Base of Kennicott formation.
  6331—
    Rhynchonella sp.
    Terebratella? sp.
    Ostrea sp.
      Rear base of Kennicott formation.
Sourdough Hill:
  6315—
    Inoceramus sp.
Dan Creek:
  6316—
    Inoceramus sp.
  6318—
    Bowlder in conglomerate of Kennicott formation.
    Halobia superba Mojsisovics?
Copper Creek:
  6322—
    Rhynchonella sp.
    Undetermined small Pelecypoda.
    Natica sp.
    Undetermined ammonite.
      Base of Kennicott formation.
Texas Creek:
  6334—
    Phylloceras? sp.
Rex Creek:
  6324—
    Irregular echinoid, crushed specimens.
    Pecten sp.

Rex Creek—Continued.
- 6324—Continued.
    - Terebratula sp.
    - Ostrea sp.
    - Anomia sp.
    - Inoceramus sp.
    - Nucula sp.
    - Arca sp.
    - Undetermined Gastropoda.
    - Phylloceras sp.
    - Shark's teeth.
        - Well up in the Kennicott formation.
- 6425—
    - Serpula sp.
    - Ostrea sp.
    - Pecten sp.
    - Arca sp.
    - Cyprina? sp.
    - Corbula sp.
    - Aporrhais sp.
    - Chemnitzia? sp.
    - Crioceras? sp.
- 6426—
    - Fragment of large ammonite.
        - Higher in the formation than 6324.
- 6336—
    - Undetermined fragmentary ammonite.

White Creek:
- 6327—
    - Ostrea sp.
        - Upper part of Kennicott formation.
- 6328—
    - Fragment of large ammonite.
        - High up in the Kennicott.

Young Creek:
- 6329—
    - Cyprina? sp. (fragment).

The absence of *Aucella* from the collections of 1909 raises a question concerning the Kennicott that can not be answered with the data at hand. If, as seems probable, its absence is due merely to the failure to find it, there is no reason to suspect any difference in age of the Kennicott sediments east and west of Kennicott Glacier. If, on the other hand, it does not occur east of Kennicott Glacier, the possibility that the basal Kennicott beds west of the glacier are older or that the sediments of the two localities are not correctly correlated is apparent.

It will be seen from the table of correlation (pp. 26–27) that Jurassic sediments are widespread in Alaska. They are found along the Pacific coast side from southeastern Alaska to the peninsula, and again on the Arctic slope, but are not known in the Yukon Basin.

Attention is directed more particularly to the Nabesna-White district, the Matanuska and Talkeetna district, and the region of Cook Inlet and the Alaska Peninsula.

The Nutzotin Mountains, northeast of the Wrangell group, consist of a great thickness of banded slates, graywackes, and conglomerates associated with limestone and sandstone beds in minor amount. Upper Jurassic fossils were collected from these beds, but the beds are very imperfectly known, and it is highly probable that they include also Triassic or even older beds. They are exposed in the canyon of Chisana River for a distance of 18 miles, and, although they are much folded, it is evident that their thickness is great.

Lower Middle Jurassic and middle and upper Middle Jurassic sediments occupy extensive areas in the region of Matanuska and Talkeetna rivers.[a] The lower Middle Jurassic rocks have a thickness of 2,000 feet, more or less, and consist of shales, sandstone, and conglomerate, with coal, associated with andesitic greenstone, tuffs, agglomerates and breccias, rhyolites, dacites, and tuffs. On these was deposited unconformably more than 2,000 feet of middle and upper Middle Jurassic shales, sandstones, conglomerates, tuff, and arkose, with coal. More than 1,000 feet of this is conglomerate.

The Jurassic rocks of Cook Inlet and the Alaska Peninsula were studied by Stanton and Martin in 1904[b] and again by Martin in the region of Iliamna Bay in 1909. They include rocks of Lower, Middle, and Upper Jurassic age. The deposits referred to the Lower Jurassic consist chiefly of water-laid tuffs, and are found at Seldovia, on the east side of Cook Inlet, and probably on the west side also. The Middle Jurassic sediments, called by Stanton and Martin the Enochkin formation, include shale and sandstone, with a few thin beds of limestone and conglomerate, and reach a thickness of 2,415 feet on the shore of Chinitna Bay. This section does not include the lower part of the Enochkin formation, yet the thickness given represents what is probably the average thickness of the formation. Upper Jurassic sediments succeeded the Enochkin formation. They were first described by Spurr[c] and received their formation name from Naknek Lake. The Naknek formation includes shale, sandstone, conglomerate, arkose, tuff, and andesite. A thickness of 5,137 feet of rocks belonging to this formation was measured by Stanton and Martin on the north shore of Chinitna Bay. Lower, Middle, and Upper Jurassic deposits thus reach a thickness of 7,500 to 8,500 feet in this region.

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[a] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: Bull. U. S. Geol. Survey No. 327, 1907, pp. 16 and following.

[b] Stanton, T. W., and Martin, G. C., Mesozoic section on Cook Inlet and Alaska Peninsula: Bull. Geol. Soc. America, vol. 16, 1905, pp. 391–410.

[c] Spurr, J. E., A reconnaissance of southwestern Alaska: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 169–171.

It has been seen from the brief description given that the Jurassic section is more nearly complete as it is traced westward from the Chitina Valley. The evidence is too incomplete to draw definite conclusions, but it appears that about the lower part of Cook Inlet Lower, Middle, and Upper Jurassic sediments are present, that in the Talkeetna and Matanuska district the Lower Jurassic is lacking, and that in the Chitina Valley both Lower and Middle Jurassic are absent. A possible explanation of this condition is that the invasion of the Jurassic sea was from the west and that the successive dropping out of the lower members from the stratigraphic section is evidence of progress in the eastward advance. This explanation, however, is not the only one, for the lower divisions of the Jurassic may yet be found in the Chitina Valley, or they may have been removed by erosion if ever present. In this connection, also, attention may once more be drawn to the fact that the known Jurassic sediments of Alaska are found on its Arctic and Pacific sides. They have not been discovered in the Yukon Basin.

QUATERNARY SYSTEM.

PREGLACIAL CONDITIONS.

So far as known, the region under discussion was elevated above sea level at the end of Eocene time and has ever since remained a land area. During and after the cessation of the mountain-building processes which raised the land to its present elevation stream erosion was active and well-developed drainage systems were formed, the area and distribution of which were perhaps very much as they are to-day. The topography of the land surface and the arrangement of the smaller drainage lines must, however, have been greatly different from those existing at present. The relief was developed by stream erosion, and in a region of such great relief the streams must have occupied narrow V-shaped valleys, with the spurs between the lateral tributary valleys overlapping in such a way as to give the streams a somewhat sinuous course around the points of the interlocking spurs. Furthermore, there must have been a heavy covering of residual soil and rock waste mantling the ridges. Stream erosion was the controlling factor in the development of the topography up to the beginning of Pleistocene time.

PLEISTOCENE ("GLACIAL") EPOCH.

CHARACTER AND EXTENT OF GLACIATION.

A change in climatic conditions inaugurated the Pleistocene epoch, with a lowering of the temperature or an increase in precipitation, or both. Ice began to form in the heads of the more favorably situated valleys, and with the gradual accumulation of ice glacial movement was started. The small glaciers which formed in the heads of a great number of separate valleys moved gradually downward to meet and merge in the main valleys. Three primary glaciers existed within the limits of this district, two of them (in the Kennicott and the Nizina valleys) moving southward and one (in the Chitina Valley) moving westward.

It is possible that the Pleistocene epoch has been represented in these mountains by more than one great ice advance, with interglacial epochs in which the ice diminished greatly in area and may even have disappeared in large part. No direct evidence has been obtained that this was the case in Alaska, as the last great ice advance obliterated all evidence of previous advances. In other mountain regions in the United States and Canada a succession of ice advances has been established, and somewhat similar conditions have probably prevailed in Alaska. The effects of earlier ice invasions may have had an important influence upon the erosion of the deep glacial valleys of this region, but the immediate effects now remaining, such as the distribution of moraines and glacial gravels, are to be ascribed to the action of the last great glaciers which filled these valleys.

As already stated, the dissection of the area in preglacial time had been accomplished by normal stream erosion. Great quantities of soil and rock waste were ready at hand for the glaciers, and these materials were incorporated into the advancing ice tongues and served as abrasives for the glaciers to use in the further grinding out of their beds. As they advanced down their valleys they encountered opposition from the spurs which projected into the valleys, and as the ice was able to override these spurs it was upon them that its erosion was most effective. This selective erosion of projecting bodies of rock was carried on continuously, and the resultant is the broad, U-shaped, troughlike gorge which is recognized as the evidence of severe glacial erosion. Erosion in the valleys, however, was not confined to the removal of overlapping spurs. The rock fragments held in the bottoms of the glaciers and pressed down upon their floors by the weight of several thousand feet of ice formed admirably adapted tools for grinding down the floors and rasping away the walls. It is impossible to estimate with any degree of accuracy the amount of glacial deepening which the trunk valleys have undergone. The difference in elevation between the mouth of a hanging tributary valley and the floor of the main valley below may be considered to offer a fair basis for estimating this deepening, and in many places this discordance is from 1,000 to 1,500 feet. Some such figure may well represent the depth to which glacial scour has lowered the larger valleys.

At the time of the last great period of glaciation the Nizina region was invaded by an ice flood which covered it to such an extent that the surface relief within the area was not more than 4,500 feet as compared with more than 7,700 feet at the present time. Only the high ridges between the principal drainage lines projected above the surface of the ice streams. The land areas were restricted to narrow, angular masses of irregular outline cut into on all sides by the smaller glaciers, which headed back toward the crests of the divides. An attempt has been made (Pl. III, in pocket) to outline the land areas which projected above the glaciers. This outline can not be considered as exact, but it must represent with a fair degree of accuracy the areas which stood up above the ice surface. Of the total area of the Nizina special map (300 square miles) only about 18 square miles remained unglaciated.

The depth at which the ice stood in the different valleys can in favorable places be determined rather closely by the present distribution of glacial moraines and erratic bowlders and by the shapes of the eroded valley walls. Certain mountains, we know, must have stood above the glaciers, because of the angular, rugged character of their summits, which fail to show the effects of the abrasive action of the ice. Other mountains, we know, must have been overridden by the ice, because of their smoothed and rounded outlines and because of the occurrence on their tops of glacial bowlders of rocks which occur in place nowhere in the vicinity of their present resting places. From such evidence it is found that in Nizina Valley, at Sourdough cabins, the top of the glacier must have stood more than 3,000 feet above the present river flat.

CHITINA GLACIER.

The Chitina Valley, which extends from the head of Chitina River near the international boundary in a west-northwest direction to the Copper River basin, is the channel which drained all the ice fields from the south side of the Wrangell Mountains as well as those from the north slope of the Chugach Range. Although only one edge of the Chitina Glacier lay within the area of the Nizina special map, it may not be out of place to give here some idea of the size of this ice tongue as a whole. At its maximum it was about 120 miles long in its own valley, and it joined the Copper River Glacier, the length of which below the junction of the Chitina is not known, although it must have been considerable. The ice field had a width for portions of its course of 20 miles and averaged about 12 miles, so that its total area was not far from 1,500 square miles, exclusive of all tributary glaciers. South of this area it was certainly close to 4,000 feet in thickness and may have been much thicker. On account of its great thickness the ice surmounted the divide between Chitina River and Young Creek and pushed to the northwest, covering the ridge between Young and Chititu creeks, so that the northern boundary of this great ice field was here the high mountain ridge north of White Creek. That it completely covered the high divides south of this ridge is evident not only from the smoothed and subdued slopes of their summits but from the presence on them of scattered bowlders of rocks strange to this immediate vicinity. In Chititu and White creeks there are numerous bowlders of greenstone, although none occurs in place within this drainage basin. Their presence here as well as that of the native copper and silver found in the placer gravels is doubtless due to the transportation of glacial ice, the bowlders in White Gulch having been brought from the east by the Chitina Glacier, and the bowlders in Rex and Chititu creeks either by the same ice tongue or from the north by the Nizina Glacier. Much of the native copper and greenstone of Young Creek was brought in by the Chitina Glacier, although there may be greenstone in place at the head of this creek. There is still a large glacier at the head of Chitina Valley, though little is known of its length or appearance.

NIZINA GLACIER.

The head of the Nizina Basin is still occupied by a great glacier, which now terminates about 11 miles above the mouth of Chitistone River. The valley below, however, shows strongly the erosion of the former glacier which moved down it. Tributary ice tongues entered the valley from both sides north of the area here considered, but within it the large branches all came in from the east. The northernmost and by far the most important branch came down the Chitistone Valley. This stream drains a basin which extends northeast to Skolai Pass and east into a range of high glaciated mountains. That the valley was the outlet for a vigorous glacier is evident from the steep-walled trough through which the stream now flows. The valley floor near the mouth of the canyon is only three-eighths mile wide, but the ice in it once reached a depth of at least 3,500 feet and was able to keep its trough cut down to grade with the floor of the Nizina Valley. Toward the lower end of the Chitistone Valley the tops of the mountains on both the north and the south sides are flat and mesa-like, and, although the valley glacier did not extend up to these mesas, they were occupied by glaciers which must have extended to their edges and cascaded down upon the valley glacier below, so that only a portion of the steep cliffs at the upper limit of the valley walls were free from ice.

Five miles south of the Chitistone a tributary ice tongue fed into the Nizina from Dan Creek. This lobe drained the ice from a much smaller basin than the Chitistone and excavated its valley much less severely. In it the depth of the ice was great, but this was due more to the damming back by the great glacier in the Nizina Valley than to its own supply, and the movement must have been comparatively sluggish. Besides receiving ice from a large number of cirques, some of which are still occupied by small glaciers, this lobe was fed by the ice sheet on the mesa to the north. This ice sheet still exists and covers most of the flat uplands, but now sends ice over its edge at only a few points.

The main valleys of Chititu and Young creeks were invaded by ice from the Chitina Glacier, which spread over the intervening ridges and made a continuous ice sheet from Chititu Creek to the south side of the Chitina Valley. Rex Creek, however, was separated by a high ridge from the Chitina ice and sent down a tributary tongue to join the great ice flood at the junction of the Nizina and Chitina glaciers.

KENNICOTT GLACIER.

The Kennicott Basin is occupied in its upper portion by a glacier which extends within 5 miles of the mouth of Kennicott River. The area of the Nizina special map includes about 10 square miles of the eastern edge of this ice tongue. A line drawn from Kennicott to the point of junction of the two principal branches of the glacier separates the white ice of the east fork from the moraine-covered ice of the lower portion. The west fork, which is the larger, heading on the flanks of Mount Blackburne, shows a banded, ribbon-like surface of lines of white ice alternating with long surface moraines. Below the junction of the two branches the white bands disappear and the glacier presents a chaotic surface of sharp hills and deep, wide-mouthed crevasses, all more or less thickly covered with débris. Part of the drainage from the melting ice runs off as streams, which flank the lower portion of the glacier on either side, but much the greater part of the water emerges from what is known as the "pothole," at the lower end of the glacier. The pothole is the mouth of a subglacial channel, and Kennicott River boils out of this opening as a gigantic spring. In winter the pothole has been known to freeze up, damming back the water until sufficient hydraulic pressure has been developed to break away the ice, when a torrent of water rushes down Kennicott and Nizina rivers, sometimes flooding the ice all the way to Copper River.

The severity of the earlier glaciation in the Kennicott Valley is comparable to that of the Nizina. The ice extended southward to join the great Chitina Glacier, which had already been swelled by the ice from the Nizina. The surface of the glacier at Kennicott then stood about 3,000 feet higher than it does to-day, and the severity of its erosion is shown by the straight lines of the contours along the mountain sides and by the complete absence of projecting spurs.

The Kennicott Glacier had within this area one important tributary, which occupied the valley of McCarthy Creek. Its course, like that of the Kennicott and Nizina glaciers, was from north to south, and its erosion was sufficient to reduce its valley to a straight, U-shaped trough. Within the area of this map all the important tributaries to McCarthy Creek Glacier came in from the east, especially from the valleys of Nikolai Creek and East Fork. At one time the ice surface stood 1,000 feet above the divide at the head of South Fork of Nikolai Creek, and it is probable that some of the ice from the Nizina Glacier moved westward over this col and then down the McCarthy Creek valley. Below Sourdough Peak the Kennicott, McCarthy, and Nizina glaciers all joined the great Chitina ice stream and moved northwestward down the Chitina Valley.

In the preceding paragraphs the attempt has been made to describe the glaciers of the region at the time of their greatest development. The individual ice lobes and their interrelations would have been different at lesser stages of development. The arrows shown on the map (Pl. III, in pocket) represent the directions of ice movement in the different parts of the area.

RETREAT OF THE ICE.

In the earlier stages of glaciation of the region the ice no doubt built up lateral and terminal moraines, but further advances destroyed or obliterated all traces of the earlier deposits. It is only those deposits that were laid down at the time of or subsequent to the maximum advance of the ice that have been preserved, and in many places even this material has been removed by stream cutting or been covered with stream deposits. There are left only a few areas of distinctive terminal moraine, having the characteristic hummock and kettle topography. Some such moraine still exists west of the lower portion of Young Creek, and some east of lower Chititu Creek, with occasional more recent patches like that on Texas Creek near the head of Copper Creek. These areas often contain lakes which occupy undrained depressions in the glacial deposits. The absence of strong moraines in most of the valleys is due, in part at least, to the vigorous cutting of the streams, which have long ago removed them. The Kennicott Glacier, which terminates near the mouth of McCarthy Creek, has remarkably little moraine around its edges, and although the surface of the lower portion of the glacier is covered with detritus the streams have removed this as fast as it has been dropped by the ice and in many places are cutting into the glacier itself.

Glacial till or bowlder clay is rather widely distributed in this area along the lower slopes of the valley walls. Its surface is generally covered by a heavy growth of mosses and timber, but fresh exposures can be seen at many places along the banks of streams. It consists of a rather dense blue clay in which are embedded bowlders, pebbles, and angular fragments of many different kinds of rock, and it is characterized by unassorted materials and lack of stratification.

BENCH GRAVELS.

As climatic conditions became less favorable for glaciation and the ice diminished from its greatest thickness the glaciers in many of the smaller drainage lines tributary to the larger trunk valleys shrank until they no longer joined the main ice lobes below. Thus the lower part of McCarthy and Dan creek valleys were free from ice while their mouths were blockaded by the Kennicott and the Nizina glaciers. In like manner the ice in the Chitina Valley had shrunk so that it was no longer able to override the ridges on either side of Young Creek, and Chititu and Young creeks had lost their ice while the Nizina Glacier still stood high in the valley to the northwest. As a result the drainage in many valleys was impeded by the ice dams across their mouths, and the streams began to fill in their basins with gravel deposits. It may be that temporary lakes were sometimes formed behind the ice barriers, but the character of the gravel deposited indicates that if such lakes existed they must have been of short duration.

Gravel fillings behind glacier dams in many places reached a great thickness. In Young Creek valley, above the portion where the creek flows north, the gravels are in places more than 500 feet thick near the center of the valley and thin out at the sides. The upper limit of the gravels is difficult to determine on account of the thick coating of moss with which the surface is covered, but it probably lies for the most part between the elevations of 3,250 and 3,500 feet. In Chititu Creek, at the mouth of Rex Creek, a similar thickness of gravels was reached. At the point where Dan Creek emerges from the mountains a great bench more than 700 feet high shows that the stream floor was graded up to that level when the Nizina Glacier still filled the valley below. In the McCarthy Creek valley a broad area was filled with gravels deposited under similar conditions. An advance by the Kennicott Glacier of only 2 or 3 miles would be sufficient to cause McCarthy Creek to begin again the grading up of its valley with gravels like those of which the gravel benches are composed.

In all of the valleys mentioned the alluvial filling was due to the presence of an ice barrier which retarded the drainage and caused the streams to build rapidly. As the great glaciers retreated and their thickness decreased the barriers to the tributary streams were lowered and they began to cut into the gravel filling which they had laid down. They did not, however, remove the filling from the whole width of the valleys, but intrenched themselves in this filling and developed deep gorges with gravel banks. Throughout much of the upper part of Young Creek and in parts of Chititu, Dan, and McCarthy creeks the streams have now cut completely through the gravels and into the rock below, leaving the valley filling as terraces or benches on either side of the streams. In Young Creek valley, especially, many lateral tributaries have also cut through the gravels, which now form interrupted benches along the slopes to the north and south of the stream.

PRESENT STREAM GRAVELS.

The larger glacier-fed streams of the area are in sharp contrast, both in appearance of water and in character of valley deposits, with the streams which do not head in active glaciers. The streams which are supplied only by melting snow and by the ordinary run-off are for the most part clear, and they are gradually cutting their valleys deeper. The glacier-fed streams, on the contrary, are supplied with great quantities of detritus by the glaciers, and during the warm season they are turbulent and heavily loaded, so that they are constantly building up their valleys with gravels and silts brought down from above. The Nizina Valley is a conspicuous example of this building process. The present flood plain ranges in width from one-fourth mile at the extreme western edge of the area mapped to more than 2 miles at its widest points. The flat is composed of gravel bars, for the most part bare of vegetation though some of the higher portions are timbered. The proportion of the flat that is covered by water at any one time not only varies greatly with the seasons, but often there is a great daily range as well. Since the water supply is largely furnished by the melting of the glaciers and of the snow on the mountains, the streams are highest in July, and in periods of high water a large part of the flat is covered. During the late fall and winter the rivers dwindle until but little water flows beneath the ice. The daily range, too, is largely controlled by the temperature, the streams being lowest in the early morning but on bright, sunny days increasing in volume until the late afternoon, when the flow is many times as large as it was early in the day.

All of these variations in volume are important factors in the transportation and deposition of débris. In high stages the streams are most turbulent and great quantities of gravel and silt are carried by them. In low stages the water becomes clearer and but little material is moved. As a result of their overloaded condition during the summer, the streams, which flow in some places as single streams and in others as intricate networks of channels, are constantly shifting their courses over the flood plains, building up bars in some places while cutting them away in others. In the Nizina Valley below Young Creek the present tendency of the river is to lower its bed, owing to the increased gradient given by the cutting down of Nizina Canyon below. Above Young Creek the valley floor is being built up, the building proceeding most rapidly at the mouths of the tributary streams. Chititu Creek has a large low-grade fan below its canyon, but the edge of this fan has reached the Nizina flood plain at only one point. Dan Creek also has a low fan extending out to the Nizina bars. The largest deposit from a tributary stream is that at the mouth of Chitistone River. Here a wide fan of low slope has crowded Nizina River over against the rock cliffs on its west valley wall, where in places all the talus slopes have been removed and the flood plain extends flush up against the limestone cliffs. This fan has also been effective in retarding the current of Nizina River above it and in aiding deposition there.

McCarthy Creek flows for the lower 10 miles of its course through a more or less narrow valley intrenched into the gravel deposits and into its rock bed, but above this portion the valley floor is broad and gravel filled.

POSTGLACIAL EROSION.

The agencies of rock weathering and erosion are very active in this region of great daily ranges in temperature, high altitudes, and steep slopes, so that the amount of rock material which has been removed since the retreat of the great glaciers has been large. The timber line throughout the district lies at about 4,000 feet or lower, although willow and alder bushes flourish above this and are sometimes found up to an elevation of 5,000 feet. Above 5,000 feet vegetation is sparse and most of the surface is bare and exposed to the agencies of weathering. Large talus slopes occur below all steep cliffs. The greenstone is perhaps most resistant of all rocks in this vicinity, and the talus accumulations below greenstone outcrops are small as compared with those below similar cliffs of the more easily weathered rocks. The Chitistone limestone follows the greenstone in its ability to resist weathering, although, as is to be expected, there are often large talus slopes below the enormous cliffs which this limestone offers. The porphyry weathers much more rapidly than either greenstone or limestone, and the sides of those mountains which are composed of this rock are almost invariably buried beneath great talus aprons. In the steep-sided porphyry mountain between the Kennicott and McCarthy Creek the talus is so abundant that few outcrops occur below an elevation of 5,000 feet and only the upper craggy portion of the mountain is free from talus. Both Triassic and Jurassic shales weather readily, the latter with the greater ease on account of its freedom from hard beds of limestone. A great amount of postglacial stream cutting has been done in the Triassic shales between McCarthy Creek and the Nizina. In the Kennicott shales of Dan, Chititu, and Young creeks the amount of stream cutting near the gulch heads has been very large. There is every reason to believe that on the south side of Chititu and on both sides of Young Creek the slopes were left smooth and free from gulches by the glacial ice. Since the ice retreated large gulches have been cut and a great amount of the easily eroded shale has been removed. The streams in these valleys have also succeeded in cutting through the thick gravels into the bed rock below.

Altogether, when the comparatively short time that has elapsed since the retreat of the ice from this area is considered, the work accomplished by erosional agencies has been surprisingly great.

ROCK GLACIERS.[a]

Among the important agencies of postglacial denudation in this district are the remarkable features which have been called rock glaciers (Pl. III, in pocket). These are rather widely distributed among the more rugged portions of the area, more than 30 occurring within the borders of this sheet. They are known to occur in other parts of the Wrangell Mountains, but here they attain exceptionally perfect development. An inspection of the topographic map shows at once many of the characteristics of the rock glaciers, but the important features, such as the surface markings, can not be shown with such a large contour interval. Although differing greatly among themselves in size, shape, and material, they have certain characteristics in common. They are usually long, narrow flows, many times longer than wide, confined in the bottoms of cirquelike valleys. Some have wide, fan-shaped heads and taper down to narrow tongues below; others are narrow above and spread out into spatulate lobes below; but the greater number are bodies of nearly uniform width, from one-tenth to one-fourth of a mile wide and from one-half to 2½ miles long. The surface slopes vary in different examples from 9° to 18° for the whole course of the flow.

On viewing one of the better-developed rock glaciers one is struck by its great resemblance to true glaciers. They all head in cirques and extend thence down the valleys. In cross section their shape is much like that of a glacier, being highest above the valley axis and sloping down sharply on the sides. Where confined in narrow valleys the rock glaciers are narrow tongues lying in the valley bottoms, but upon emerging from their restricting walls they spread out into broad lobes. Some have distinct lateral moraine-like ridges and all show a more or less well-marked longitudinal ridging.

The materials of which the rock glaciers are composed are the blocks and fragments of angular rock such as go to make up the ordinary talus slope, the fragments being derived from the walls of the cirque at the valley head. The variety of rock found in any rock glacier therefore depends on the materials found in the cirque walls—porphyry, limestone, greenstone, or shale, as the case may be. The individual rock fragments vary in size from fine stuff to blocks several feet in diameter in exceptional cases. Six inches would perhaps be the average size in these rock glaciers which are composed of porphyry, while in the greenstones and limestones the average is larger and in the shales it is smaller than this.

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[a] Capps, Stephen R., Rock glaciers in Alaska: Jour. Geology, vol. 18, pp. 359–375.

In many of the rock glaciers the fragmental rock extends all the way to the head of the cirque, with no ice visible and little or no snow on the surface. In several cases, however, the rock glaciers grade into true glaciers at their upper ends, without any sharp line of demarcation, so that there is a complete gradation between the two.

The surface markings are characteristic and in some measure are systematic in their arrangement. In the upper portions there are usually many parallel longitudinal ridges a few feet high, separated by troughlike depressions (Pl. IX, *B*, p. 56). Toward the lower end of each rock glacier which has an opportunity to spread out into a broad lobe the longitudinal ridges become less prominent and finally disappear entirely, giving place to concentric wrinkles which parallel the borders of the lobe. The sides of the flow below the cirque are usually separated from the rock valley walls by a sharp trough, and at their lower ends the flows steepen to the angle of rest for the material. The whole appearance gives one a decided impression of movement, as if the material had moved forward from the cirques in somewhat the manner of a glacier, the longitudinal lines simulating moraine lines.

The marked resemblance of these flows to glaciers led to the suspicion that ice must be in some way responsible for their movement. To determine if this were the case, a number of the rock glaciers, 7 or 8 in all, were dug into, and in each instance clear ice was found. This was not massive ice like that of a glacier, but interstitial ice, filling the cavities between the angular fragments and forming with the rock a breccia, with the ice as the matrix. The depth below the surface at which ice was found varied according to the elevation of the rock glacier and to the portion of it examined. Toward their lower ends the ice lay too deep to be found by any shallow excavations that there was opportunity to make. Farther up, toward the cirques in which they head, the ice was usually found within a foot or two of the surface if a depression was dug into. The surface of the ice-filled portion, being determined by the depth to which melting takes place, follows roughly the surface of the flow, so that along the troughs between the ridges running water could be found on a warm day following shallow channels in the ice-filled talus.

The rock glaciers are quite different from true glaciers, although in those cases where the rock glacier is a continuation of the lower end of a true glacier it may be impossible to draw a line separating the two. For the formation and existence of a glacier it is necessary that in the head of the basin occupied by ice there should be an annual surplus of snowfall over melt. When the amount of snowfall becomes less than the amount which melts and runs off, the glacier will dwindle and finally disappear. The greater number of rock glaciers, on the other hand, are found to head in cirques in which all or practically all of the winter snow disappears during the summer. In a true glacier, no matter how heavily moraine covered it may be, there is always a tendency to crevasse where the ice rounds a bend or passes over an irregularity of its bed, and great irregularity of surface is common at the lower end, where the melting ice allows the overlying moraine to cave in. In the rock glaciers no crevasses were seen, even in places where abrupt changes in the grade of the bed occur, and large cave-in pits are wanting. Irregularities of this kind, however, are not to be expected if the rock glaciers are composed, as they seem to be, of talus, with ice only in the interstices, for the talus itself is self-supporting without the ice, and the shape of the surface would be but little changed if the ice should all melt out. This is true, however, only of those flows which have not glaciers at their upper ends. Of those which head in glaciers, the upper ends would of course be profoundly altered by the melting of the ice, and these effects would be seen just as far down the flow as massive glacial ice had existed. The rock glaciers differ from true glaciers in that, although they advance spasmodically, they never retreat, for the flow retains its form even after the ice has melted out and motion has ceased. Little has been published concerning features of this kind. Certain "stone rivers" in the Falkland Islands have been described by Thomson,[a] Andersson,[b] and others, but according to Andersson's interpretation these "stone rivers," which are now streams of angular blocks of rock, were formerly composed of fine mud, with the blocks of rock buoyed up and carried along by the viscous flow of the mud. The movement has now ceased, and much of the fine material has been removed by running water.

The closest analogy to the rock glaciers seems to be found in the "rock streams" of the San Juan Mountains of Colorado, described by Cross and Howe[c] in the Silverton folio and more recently by Howe[d] in a separate publication. Both are composed of angular talus from high mountains, and the similarities of appearance and surface configuration are striking. The San Juan flows have been referred to in a textbook[a] as "talus glaciers," and the authors are of the opinion that in many cases snow and ice have had some part in their development. Cross and Howe formerly believed that the position and form of the rock streams were due to glacial transportation, but the absence of ice and some other considerations led them to the opinion which they now hold, that the rock streams were formed by landslides which came down "with a sudden violent rush that ended as quickly as it started." Up to the present time no opportunity has offered to prove conclusively by a series of observations extending over a considerable period of time that these rock glaciers are in motion or to determine their rate of movement. There are, however, a number of significant facts which seem to make this conclusion necessary.

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[a] Thomson, Wyville, The Atlantic, p. 245.

[b] Andersson, J. G., Solifluction, a component of subaerial denudation: Jour. Geology, vol. 14, 1906, pp. 91-112.

[c] Cross, Whitman, and Howe, Ernest, Silverton folio (No. 120), Geol. Atlas U. S., U. S. Geol. Survey, 1905, p. 25.

[d] Howe, Ernest, Landslides in the San Juan Mountains, Colorado: Prof. Paper U. S. Geol. Survey No. 67, 1909.

Although on account of climatic conditions most of the cirques in which the rock glaciers head are unable to support true glaciers, they are on the border line of glacial conditions, and although the snows may all melt away on the surface during the summer the ground remains permanently frozen a short distance below the surface and ice in the interstitial openings of a talus mass may remain unmelted indefinitely. Furthermore, a few of the rock glaciers have true glaciers at their heads which extend downward as far as climatic conditions are favorable and are continued below by rock glaciers whose ice is protected from the sun by the heavy coating of débris, and into such rock glaciers it is probable that a tapering tongue of true glacial ice extends down a considerable distance. But this glacial ice is not necessary to their movement, as is shown by those rock glaciers which are unconnected with true glaciers. In addition to the favorable climatic conditions, the exceptionally perfect development of these features in the Nizina district is due to the rugged character of the mountains, with cirques having steep heads and sides, and to unusually favorable conditions for rapid rock weathering and talus accumulation.

The history of the rock glaciers of this district is considered to have been as follows:

As the ice of the last great epoch of glaciation began to retreat and its area to contract, the head and side walls of many of the cirques, steepened by glacial undercutting and by bergschrund sapping, were exposed to the rapid weathering characteristic of bare rock surfaces in the high altitudes of this region. In many of the cirques the rock waste streamed down from the cliffs upon the glacier below and was gradually carried away by the ice and concentrated at its lower edge. Here in the usual order of events it would have been deposited as a terminal moraine, though differing in character from the common forms of terminal moraine in the preponderance of angular, talus-like material and in the proportionately smaller amount of mud and rock flour which form so important a part of the moraines of active glaciers. Here the small, fast-dying glaciers were eroding but little and were almost overwhelmed by the débris supplied them from the cliffs above. Into the débris toward the lower edge of the glacier the waters from melting ice and snow and from rains sank and froze and gradually filled the interstices up to a point below the surface where melting equaled freezing. In these ice-cemented masses a sort of glacial movement was started. As the climate became still milder, in many cirques the winter snows all melted away during the summer, so that conditions for ordinary glacial activity no longer existed, but the bodies of talus which reached the cirque floors became filled with interstitial ice and the consequent movement of the mass in a glacier-like way has continued, although no doubt all true glacial ice has now disappeared from many of the rock glaciers. It is certain that much snow is still carried down upon the surface of the rock glaciers in slides of snow and rock during the winter and spring, and considerable quantities of it may become covered by débris and incorporated into the rock glaciers, but this snow probably forms only a small part of the total mass of the flow.

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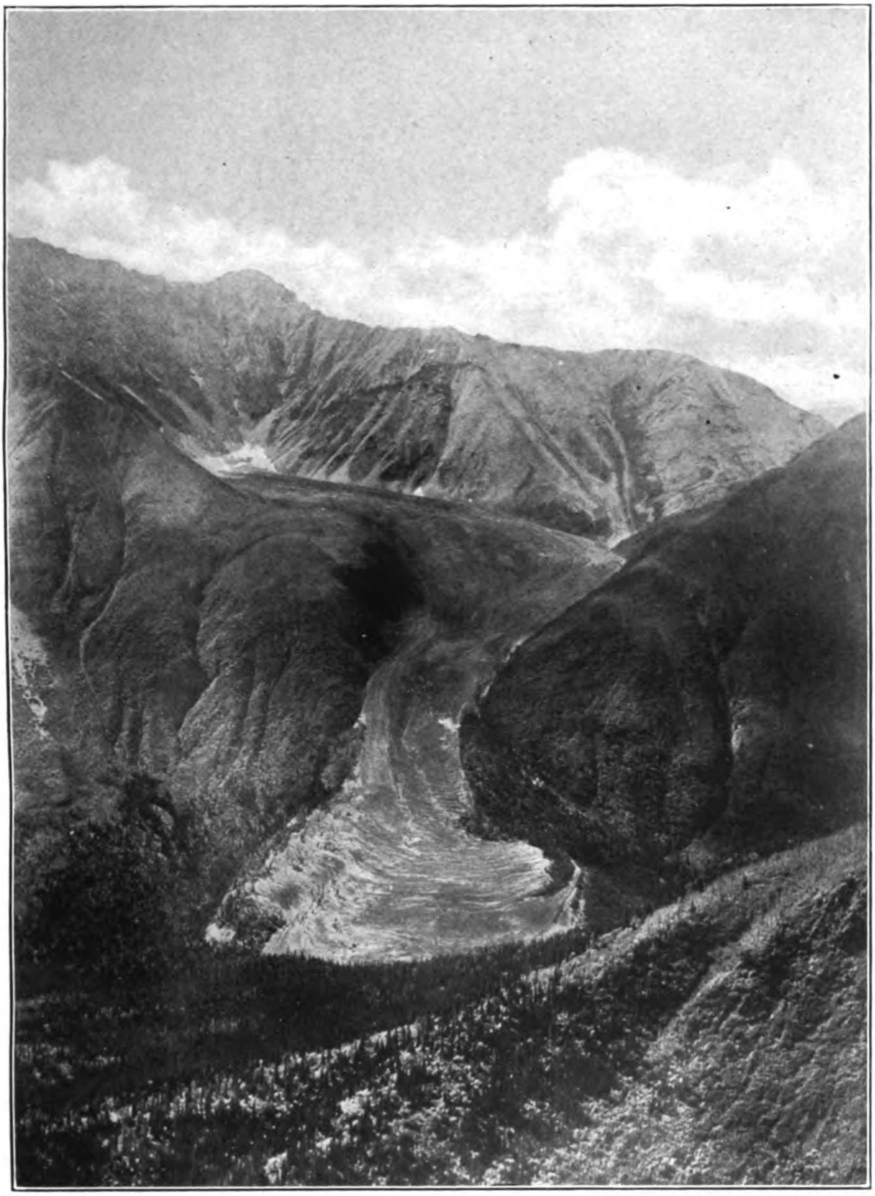
[a] Chamberlin, T. C., and Salisbury, R. D., Geology, vol. 1, 1904, p. 220.

The succession of events outlined seems to be well established in this region, where are now to be seen all the stages, varying from apparently active glaciers with short rock glaciers below to long rock glaciers in which no glacial ice is seen, in valleys where all the snow disappears during the summer; yet in these latter the slow movement seems still to be in operation, the rate of movement in each flow being controlled by the supply of talus from above and by the shape and grade of the floor over which it moves. The rock glaciers are therefore the true successors of real glaciers.

The rock glacier which lies on the west side of McCarthy Creek, three-fourths of a mile above the mouth of East Fork (Pl. VIII), though by no means the largest in size, offers a most instructive example for study, as it presents in a typical way many of the characteristic features of all of the flows. It heads in a glacial cirque in a mountain composed largely of porphyry but having many inclosed masses of black shale, the peaks at the cirque head reaching a height of 6,315 feet. The rock glacier occupies the cirque floor below an elevation of 5,250 feet, with talus slopes extending upward above it for about 200 feet. Above the talus the whole face of the mountain is of bare, rugged cliffs of porphyry and shale, both of



ROCK GLACIER ON McCARTHY CREEK THREE-FOURTHS OF A MILE ABOVE MOUTH OF EAST FORK.

Showing the source of supply in the talus cones above, also the surface markings—longitudinal in the upper portion, concentric below. See page 56.

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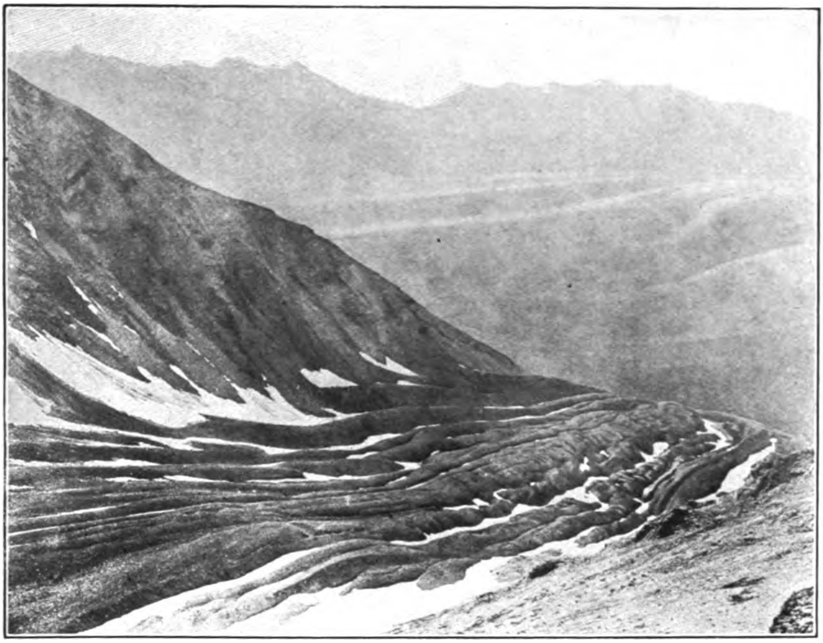
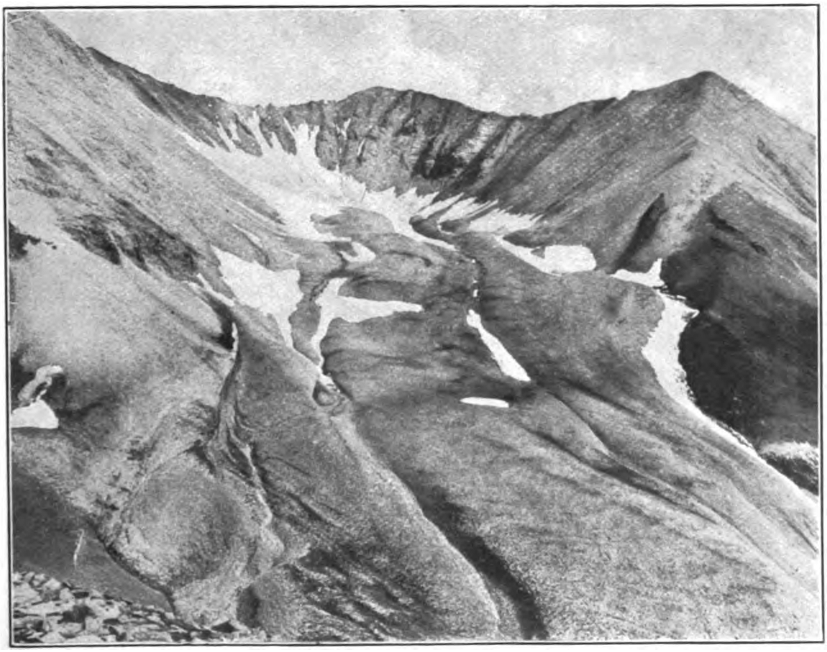


A. ROCK GLACIER NEAR HEAD OF NATIONAL CREEK.

Showing the characteristic longitudinal ridges and their relation to the talus slopes on the rock walls above. See page 57.



B. HEAD OF ROCK GLACIER ON LITTLE NIKOLAI CREEK.

The cirquelike valley, with its abundant talus slopes feeding down to the rock glacier, is free from true glacial ice. See pages 53, 57.

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which weather easily, so that the formation of talus is unusually rapid. The elevation of the valley head is not sufficient for the maintenance of a true glacier, and during the summer practically all of the snowfall disappears. By July 4, the time of observation, only small snow banks remained in sheltered places.

The rock glacier heads in the talus cones which have been built up at the base of the steep rock cliffs. These cones, although constantly added to by waste from the rapidly weathering cliffs above, have nowhere been able to attain large size, the materials evidently having moved on down the valley as a rock glacier as fast as they were supplied from above. From the base of each of the more vigorous talus cones a smooth ridge extends down the rock glacier, seeming to show that the forward movement has on the whole been uniform and continuous. Parallel longitudinal ridges of this kind characterize the surface of the upper three-fourths of the flow. The cirque basin above an elevation of 4,000 feet is a hanging valley, but below this level it joins the broad U-shaped valley of McCarthy Creek with an abrupt change of gradient. As it passes over the lip of the hanging cirque the rock glacier cascades steeply down the valley side, and on reaching the gentler slope below, being no longer confined by restricting valley walls, it spreads out in a great lobe along the valley bottom. In this lower lobe the longitudinal surface markings dwindle out and disappear, giving place to a set of beautifully developed concentric wrinkles which parallel the borders of the lobe (Pl. IX, *B*). The origin of these wrinkles is not clear, but they strongly suggest rings of growth and may represent the amount of annual movement of the rock glacier.

At its foot the flow has pushed across the valley bottom to the base of the east valley wall, thus indicating clearly by its position that it was formed after the retreat of the McCarthy Creek Glacier beyond this point. The creek has been crowded to the east and occupies a narrow channel between the foot of the rock glacier and the rock valley wall. The foot of the flow is being rapidly cut away by the stream and in places shows a face 75 to 100 feet high in which the slope is about 35°, or the angle of rest for the material. The creek, although of large volume and steep gradient, has been unable to do more than keep its channel open along the foot of the rock glacier, and it seems evident that the flow is moving forward as fast as the stream can cut it back.

Another rock glacier which heads in the same porphyry-shale mountain as the one just described flows in a northwest direction into the valley of National Creek, a tributary of the Kennicott (Pl. IX, *A*). It is remarkable for the unusually strong development of the longitudinal ridges in its upper portion, and these ridges show well their mode of origin in the separate talus slopes on the rock walls above.

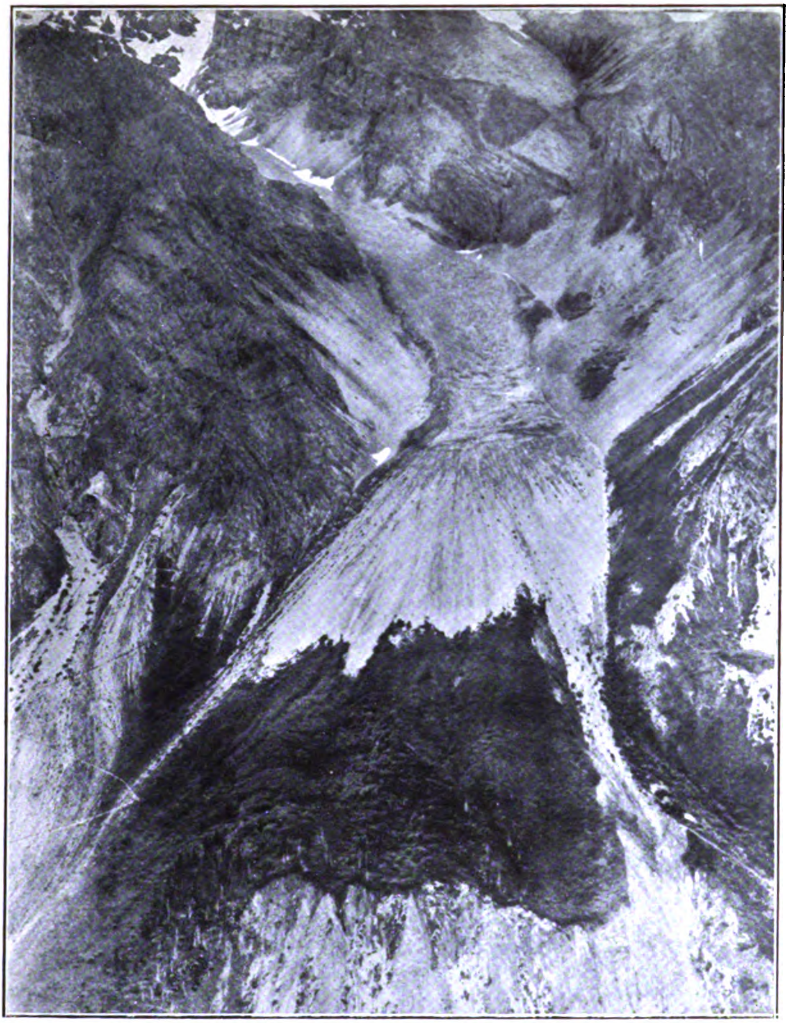
The flow in Amazon Creek, just east of the Kennicott Glacier, and that in the north head of White Creek are notable for their great length as compared with their width and for the uniformity of their slopes from one end to the other. The surface of the former has a slope of 15° and that of the latter 12°.

The rock glacier which heads in the limestone mountain half a mile northeast of the Bonanza mine and flows eastward shows at its upper end all of the characteristics typical of these flows, but at the mouth of the hanging valley in which it lies it streams down to McCarthy Creek as a symmetrical talus cone (Pl. X, *A*). If the material had come down suddenly as a landslide, no such perfect talus cone would have formed, and its presence indicates that the material of which it is composed was supplied slowly. Furthermore, evidence that this rock glacier is still moving is given by the fact that the talus is still being supplied at the head of the cone and is invading the patch of bushes on its side.

The two large rock glaciers, one on the south and one on the northwest side of Sourdough Peak, are both of the type which originates in narrow cirques but spreads out into broad lobes below the point where the cirque walls restrict it. The glacier on the south side of this mountain is especially noteworthy on account of the great expanse of the flow below as compared with the narrow limits of the cirque in which it originated.

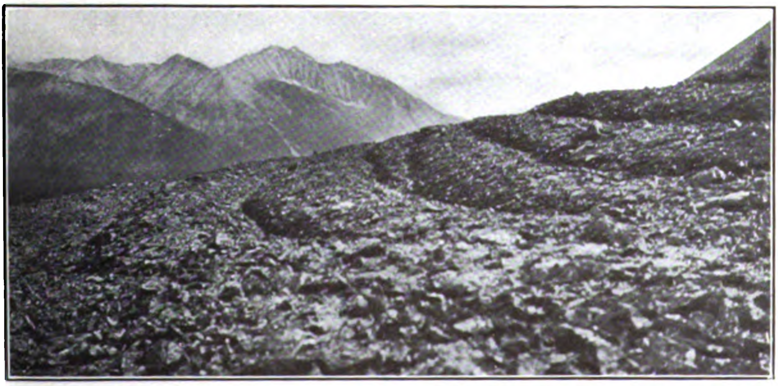
In conclusion, observation has led to the belief that these rock glaciers have moved and that many of them are still moving in much the same way as glaciers, and that, although glacial ice may be and doubtless is present in a few of them, it is not necessary to the movement, which may be due altogether to ice in the interstices. Furthermore, there is no evidence that the flows came down suddenly as landslides, but there are strong reasons for believing that they moved down slowly. The facts and considerations which have led to the conclusion that the flows did not come down suddenly but slowly and that some of them are now in motion are noted below.

1. The remarkable resemblance in position and form of the rock glaciers to true glaciers in the immediate vicinity.
2. The direct connection and perfect gradation between true glaciers above and rock glaciers below.
3. The presence of interstitial ice at no great depth below the surface in all the rock glaciers which were dug into.
4. The longitudinal ridges of the upper portions of many of the flows that can be traced directly to active talus slopes.



A. ROCK GLACIER IN A TRIBUTARY OF McCARTHY CREEK NORTHEAST OF BONANZA MINE.

At the mouth of its hanging valley it breaks down into a great talus cone. See pages 58, 59.



B. DETAIL OF SURFACE OF ROCK GLACIER ON TRIBUTARY OF McCARTHY CREEK.

The rounded ridges in the foreground are the concentric ridges which characterize the lower portion of the flow.

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5. Nowhere have the talus slopes at the cirque heads been able to form any considerable accumulations upon the surface of the rock glaciers. This seems to be strong evidence that the talus has moved down valley as fast as it has been supplied.

6. Most of the rock glaciers have a steep slope at the lower end, where the gently sloping surface of the upper portion breaks down at the edge at an angle of rest as steep as the material will retain. On this steep face the rock fragments show bare surfaces, while the talus on the surface above is usually lichen covered. This seems to show that the material is moving forward fast enough to prevent erosion at the lower end from establishing drainage lines on the face of the flow and from reducing it to a low-graded slope.

7. McCarthy Creek, a swift stream of large volume, which is now actively cutting into the lower edge of a rock glacier on its west side (described on pp. 56–57) that has been in existence long enough for large spruce trees to grow upon its surface, has so far been unable to do more than keep open a narrow channel along the foot of the flow. There is no evidence that the rock glacier ever extended 75 feet farther eastward to the rock bluff on the east side of the valley. It would be surprising if this mass of material, coming down with a violent rush, should have failed by just the width of the creek to cross the valley, and if the stream, which is now actively cutting into the face of the flow, should have been unable to do more than keep its channel open. It appears more probable that the slowly advancing edge of the rock glacier had forced the stream to its present position and that the edge of the flow is now farther advanced than it has ever been before.

8. There is no evidence that large landslides have taken place in this region if these flows are not landslides. None were seen below the miles of prominent cliffs of the area, though ordinary talus cones are abundant.

9. The rock glacier on McCarthy Creek, northeast of the Bonanza mine (Pl. X, *A* and *B*), ends below in a well-developed talus cone. If the material had come down suddenly as a landslide, no such perfect talus cone would have been formed. The presence of the cone indicates that the material was supplied slowly, enabling the cone to grow symmetrically. The cone is still growing, as can be seen from the way in which the talus from above is invading the patch of bushes on its face.

10. Wherever two rock glaciers from adjacent cirques join to form a single flow the point of junction shows that the two branches have flowed together synchronously, without any evidence that the flow from one branch has come down and overridden that from the other.

IGNEOUS ROCKS.

TRIASSIC OR PRE-TRIASSIC.

NIKOLAI GREENSTONE.

CHARACTER OF THE FORMATION.

The Nikolai greenstone resembles a sedimentary formation in its structural features. It is made up of flows of basaltic lava that succeed one another like beds laid down in water. The beds or flows are usually of considerable thickness, measured in tens of feet rather than in single foot units, and the bedded appearance is more evident when a large mass of the greenstone is seen from a distance great enough to give a comprehensive view of its larger features.

The color of the weathered surface is grayish green, but in places it has a reddish hue. A fresh surface is dark olive or grayish green. In texture it varies from a dense, rough, fine-grained rock in which individual crystals can not be distinguished to a medium-grained porphyritic rock. Many of the flows are amygdaloidal and have a spotted appearance, due to the cavity fillings. Some of the spots or amygdules are light gray or almost white, like quartz or calcite; others are dark green or gray. Quartz is present but is not so frequently seen filling cavities as calcite, yet these two minerals are not the only ones that produce light-colored amygdules. Amygdaloidal greenstone bowlders in Chititu Creek contain large spherulitic aggregates of white crystals, believed to be thomsonite. This rock, however, was not seen in place. Dark-colored amygdules are more common than the light ones and for the most part consist of chloritic or serpentinous material. In many places the cavities of the lavas were elongated and distorted before their present mineral filling was introduced, so that the amygdules have peculiar irregular forms. The cavities appear to have been distributed throughout the flows from top to bottom, for no evidence of their being more abundant at the upper than at the lower surface was observed. This is one of the reasons for suspecting that the lava was poured out under water, since the weight of the water resting on the surface of the lava would prevent in large measure the expansion of included gases or steam; yet it is admitted that no proof of their submarine origin has been discovered. Interbedded tuffs and shales were not found in the greenstone. Frequently a weathered surface of the greenstone is seen where the amygdules have been dissolved out, leaving a vesicular rock that probably resembles closely the original lava flow.

A newly broken surface of the greenstone would hardly lead one to believe that chemical alteration had taken place to any considerable extent, for the rock appears to be fairly fresh, yet microscopic examination of the sections shows that the alteration is advanced and is general.

The Nikolai greenstone is less obtrusive in its topographic expression than either the shales or the limestone. It forms steep slopes and ragged mountain tops, but the greenstone mountains do not possess the sharp, angular outlines of the shale mountains or the high wall-like cliffs and the pointed spires of the limestone. Neither do the lower greenstone hills present the smooth, rounded contours of the glaciated shale ridges on either side of Young Creek. The greenstone resists decay, but it has numerous joints and fracture planes and rapidly breaks down under northern climatic conditions. This accounts for the roughness of its ridges, the absence of smooth perpendicular cliffs, and the vast quantity of angular blocks below its large exposures. Such blocks do not disintegrate like the shales, so that greenstone pebbles and bowlders form a conspicuous proportion of the gravels and other unconsolidated deposits. The greenstone, like the Chitistone limestone, resisted strongly the distorting forces that are so plainly expressed in the folding of the McCarthy shale. There is even less evidence of folding than in the limestone, but it is apparent from field observations that adjustment to pressure by faulting has taken place extensively.

PETROGRAPHIC DESCRIPTION.

Thin sections of greenstone studied with the microscope show that the rock is a typical diabase now much altered. The principal constituents are feldspar and colorless pyroxene. The feldspar is labradorite, occurring in lath-shaped crystals, and in nearly every section is more or less altered. Pyroxene fills the spaces between the feldspars. It has been less resistant to alteration than the feldspar and is largely altered to a serpentinous or chloritic material. Accessory minerals are magnetite or ilmenite and chalcopyrite; olivine and iddingsite are rare. The principal alteration minerals are serpentine or chlorite, calcite, and perhaps quartz.

Cavities in the greenstone were abundant, but have been filled with secondary minerals such as chlorite, delessite, calcite, and, rarely, quartz. Many of the amygdules show an outer coating of chloritic material and an inner filling of radiating delessite crystals, in some sections associated with calcite. An opaque decomposition product is common.

DISTRIBUTION.

The Nikolai greenstone underlies conformably the Chitistone limestone and took part in the folding and faulting that the lower part of the limestone underwent. Its distribution, therefore, is related to that of the limestone, and most of its outcrops represented on the map lie in a narrow belt on the south of the limestone belt that is practically continuous and extends southeastward from the northwest corner of the mapped area to the head of Texas Creek. This belt has its greatest width on Nizina River. A branch extends eastward up Chitistone River and then southeastward into the valley of Glacier Creek, a northwestward-flowing tributary of the Chitistone just beyond the eastern limit of the area mapped. The ridge between Dan and Glacier creeks is capped by a broad, flat syncline of limestone pitching gently northwest, but the base of this ridge wherever it is exposed is greenstone. Greenstone is exposed on both sides of Chitistone River. It dips below the gravel floor of Nizina River north of the Chitistone but rises to view again on the west side and continues north half a mile or more till it is cut off by a fault beyond the limits of the area mapped.

In places only a veneer of conglomerate or shale of the Kennicott formation covers the Nikolai greenstone and small isolated patches of the greenstone appear where the thin covering has been removed. Such patches are seen about National Creek and south of Nikolai Creek. Two small patches of greenstone appear as islands in the gravels of Nizina River, and another, exposed through faulting and erosion, lies on the north side of Copper Creek.

THICKNESS.

It is impossible to determine the thickness of the Nikolai greenstone from observations in the area under consideration, for nowhere within this area is the base of the greenstone exposed. Furthermore, it is not certain that the base of the greenstone is exposed in other parts of Chitina Valley, although it is reported in the Chitistone River basin, and it seems probable that certain tuffaceous and shale beds in the Kotsina Valley may represent it.

The figures to be given represent, therefore, only that part of the formation exposed immediately below the Chitistone limestone—that is, the upper part. One of the best localities for measurements is on the east side of Nizina River, just north of Dan Creek. The dip of the limestone and greenstone is low to the northeast. Unless the greenstone is reduplicated by faulting, its thickness at this locality is at least 4,000 and possibly 5,000 feet. The conditions for measurement in the mountain on the west side of Nizina River are less favorable, but there appear to be not less than 4,500 feet of greenstone exposed there. About 2,000 feet are exposed on the east side of McCarthy Creek and 3,500 feet in the ridge on which the Bonanza mine is situated. Between Bonanza Creek and Kennicott Glacier a thickness of over 4,000 feet of greenstone is exposed. Faults are difficult to locate in the greenstone unless some of the other formations are present to give a clue to their existence, and it is recognized that faults of sufficient importance to impair the value of the measurements given may have escaped notice. It is highly probable, however, that the thickness of greenstone in the Nizina district approaches 4,500 feet, and there can be little if any doubt that it is over 4,000 feet.

Schrader and Spencer estimated roughly the thickness of the Nikolai greenstone in the upper part of Kotsina Valley at 4,000 feet.[a]

AGE.

Inasmuch as the Nikolai greenstone is composed of lava flows and so far as known does not contain intercalated fossil-bearing beds, the determination of its age depends on its relation to the formations with which it is associated. The greenstone may perhaps contain intruded sills of rock similar in composition to the flows, but for the most part it is made up of lavas that were poured out before the Chitistone limestone began to be deposited. It can not therefore be later than Upper Triassic. Unfortunately no evidence has been collected to fix a lower age limit. North of the Nizina district, in the valley of Skolai Creek and about Skolai Pass and the head of White River, the massive upper Carboniferous limestone is overlain by thin shale beds, tuffs, and lava flows. These overlying beds are believed to rest on the limestone conformably. The lava flows increase rapidly in amount as the succession is followed upward until they finally predominate. There is a possibility that the Nikolai greenstone represents the upper part of these lavas overlying the Carboniferous limestone, in which case their age would be Triassic. Brooks and Kindle have presented evidence to show that Triassic sediments along the upper Yukon rest conformably on limestone of the same age as the limestone on White River.[b] There is therefore some degree of probability that a similar relation of Carboniferous and Triassic formations of the Wrangell Mountains may sometime be established. A comparison of the Nikolai greenstone with the rocks south of Chitina River is of interest but throws little light on the age of the greenstone. The rocks south of the Chitina are chiefly sediments, schists, graywackes, and limestones, all much metamorphosed rocks. Their age is not known but they are usually referred to the Paleozoic. The degree of alteration in them is far greater than in the greenstone, and if this fact may be used as evidence the greenstone is considerably younger. With our present knowledge it is hardly possible to say anything more definite concerning the age of the greenstone than that it is older than the Chitistone limestone and probably is Triassic.

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[a] Schrader, F. C., and Spencer, A. C., The geology and mineral resources of a portion of the Copper River district, Alaska: Special publication of the U. S. Geol. Survey, 1901, p. 42.

[b] Brooks, A. H., and Kindle, E. M., Paleozoic and associated rocks of the upper Yukon, Alaska: Bull. Geol. Soc. America, vol. 19, 1908, p. 305.

JURASSIC OR POST-JURASSIC IGNEOUS ROCKS.

QUARTZ DIORITE PORPHYRY INTRUSIVES.

LITHOLOGIC CHARACTER.

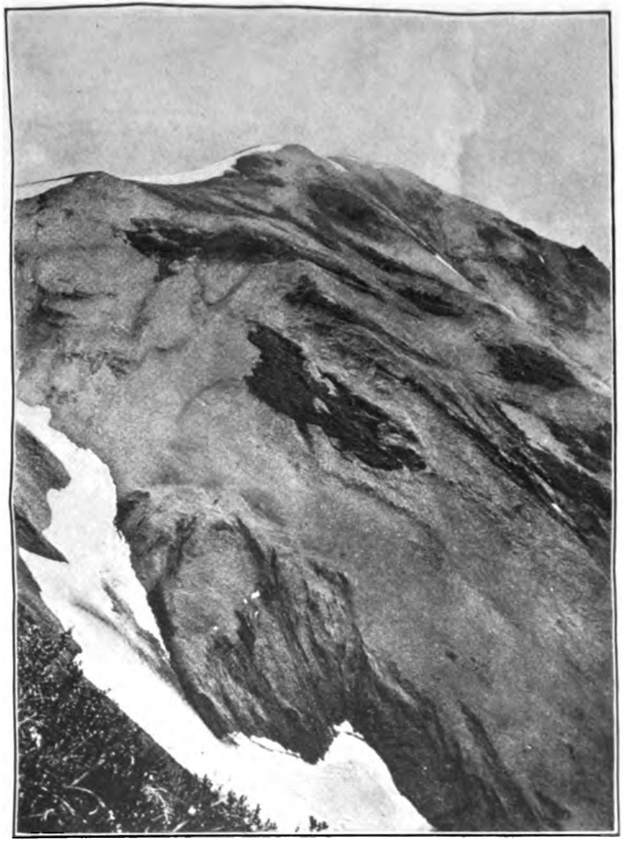
Light-colored porphyritic intrusive rocks are abundant in the Kennicott formation and are confined almost entirely to that formation, for it is a remarkable fact that intrusives are rare in the Triassic sediments and the greenstone. These intrusive rocks occur in the form of laccoliths, dikes, and sills. They show considerable differences in texture and vary from fine-grained, almost aphanitic phases to distinctly granular phases in which larger crystals or phenocrysts of feldspar and quartz are included. The color, too, varies from almost white to creamy white and various shades of gray and brown. Small phenocrysts of quartz with perfect crystal outlines are common, but as a rule the more abundant feldspar crystals are less distinct owing to chemical alteration that has taken place. It seems rather remarkable that the rock should be so fine grained as it is in some of the larger intrusives and that it should have had so litle effect on the shales into which it was intruded.

The porphyries show many stages of alteration, from intrusions that look perfectly fresh to those in which the feldspars are almost wholly decomposed and the rock has a dull, lifeless appearance. A curious banded arrangement of alteration products was noted in some of the light-colored, fine-grained intrusives. Different stages in the advancement of alteration are indicated by concentric zones of yellowish-brown and white color, which show that the chemical changes proceeded in an orderly way from the surface toward the center of each joint block.

In many places large masses of black shale have been caught up in the body of an intrusive and stand out in a most conspicuous way against the lighter-colored porphyry background (Pl. XI, A). Some of these intruded shale masses are half a mile in length along their outcrops and give the appearance of thin shale beds between very thick porphyry sills. In general, however, the included shale masses are much smaller.

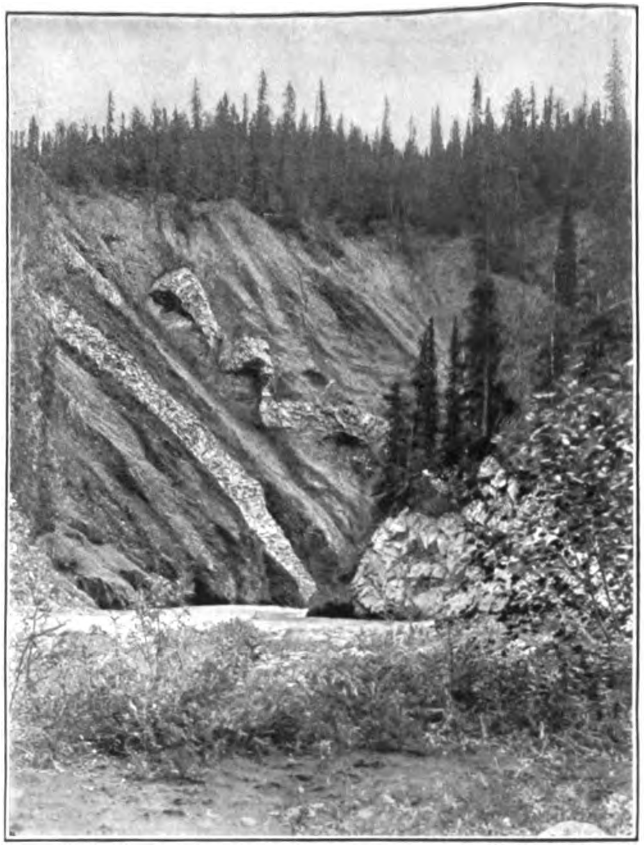
The porphyries resist decomposition but readily break down into slabs and angular fragments which give rise to extensive talus slopes, or "rock slides," as they are locally called. Such débris, because of its light color and its resistance to decay, gives character to slopes of loose material, and, although the dikes or sills from which it came may form only a minor portion of the rock mass, it almost completely hides the presence of shale or other kinds of rock.

Dikes and sills are numerous but present no unusual features further than that some of the sills persist for long distances and in



A. NORTH END OF PORPHYRY PEAK, SHOWING INCLUSIONS OF BLACK SHALE IN PORPHYRY.

See page 64.



B. PORPHYRITIC INTRUSIONS IN BLACK SHALE OF KENNICOTT FORMATION ON McCARTHY CREEK.

See page 65

places take the form of long overlapping lenses. There is a marked tendency for the intruded rock to follow bedding planes rather than to cut across the beds, so that the sills are more numerous than dikes. Some of the sills in the black shales on the south side of Copper Creek valley continue uninterruptedly for several miles and are such distinct features that the prospectors have given them numbers, as the first, second, etc. They vary in thickness from a foot or two to 100 feet and give valuable aid in determining structure in the shales.

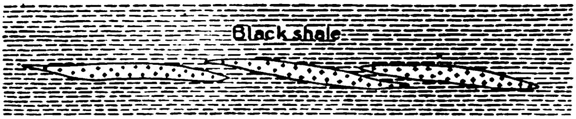


FIGURE 4.—Diagram showing the overlapping of lenticular porphyry sills in the black shales south of Copper Creek. Some of the lenses are 10 to 15 feet thick.

A good example of the way in which the porphyry dikes cut the black shales is given in Plate XI, *B*. (See also fig. 4.)

PETROGRAPHIC DESCRIPTION.

Microscopic examination of thin sections of the porphyry intrusives shows that perfectly fresh unaltered specimens are hardly to be found and that alteration products are practically always present. The rock has a fine-grained groundmass consisting chiefly of feldspar more or less altered and a little quartz in which are phenocrysts of feldspar and quartz. Various degrees of crystallization appear in the groundmass, but its perfection may be obscured by chemical alteration that has taken place since the magma consolidated. One or two of the sections studied are from specimens in which crystallization had not proceeded far when it was interrupted by cooling of the intrusive rock. These sections show a fine-grained groundmass, almost isotropic, filled with tiny forked skeleton laths or crystals of feldspar. Most sections, however, show a more advanced degree of crystallization. The feldspar is of the more acidic plagioclase variety. Zonal phenocrysts give an opportunity to determine that they belong mostly to the oligoclase-andesine series. Orthoclase appears in a few specimens. Quartz in rounded plates or with embayments is not uncommon, but for the most part the outlines are sharp and angular. Brown mica is usually present, as are also shreds and scales of colorless mica. Hornblende is the next most common ferromagnesian mineral. Many of the crystals are much altered, and in some sections the former presence of hornblende is known only by the decomposition products taking the form of the characteristic hornblende cross section. Pyroxene was found in one specimen. Most sections show a black metallic mineral like magnetite and brown iron-oxide stain.

Alteration begins in the feldspars and results in the production of fine scales of a highly refractory mineral, probably muscovite, that appear in fractures and along some of the zonal bands of the phenocrysts. Calcite is a common secondary mineral and results from the decomposition of hornblende and of feldspar, yet it may have been introduced in part by circulating water. Calcite resulting from decomposition of hornblende is associated with iron oxide.

DISTRIBUTION.

Porphyritic intrusions are present in the black shales of the Kennicott formation in all parts of the Nizina district, but they have their greatest development north of Nizina River. Porphyry Peak and Sourdough Peak are composed largely of porphyry, as is also the mountain north of Nikolai Creek. The upper parts of all three are made up almost entirely of porphyry in which are included masses of black shale. These laccoliths form a hard resisting cap on the softer shale base and doubtless have been an important factor in protecting the shale from erosion. There are no such large porphyry masses in the black shales southeast of Nizina River, but sills and dikes are numerous in all the shale mountains from Dan Creek to Young Creek. They appear to be more numerous on Dan and Copper creeks and about the head of Rex Creek than they are farther south, but the steep, bare sides of the mountains in the former locality give better opportunities for discovering them than the lower timber and moss-covered slopes of the latter. The preference shown by the intrusives for the black shales is considered as evidence that the molten rock was able to force itself into the black shales more easily than into the lower formations or the upper part of the Kennicott formation. It is remarkable, when one considers their number in the Kennicott formation, that so few intrusives are present in the Triassic sedimentary formations and the greenstone. Special attention was given to this point during the course of field work, since it was assumed that the intruding rocks must cut the older formations in order to reach the overlying younger formations and that traces of some of the conduits through which the melted rock rose would be found. A few dikes were discovered, but they do not seem to bear any proper relation in size and number to the amount of intruded matter in the shales, so that one is forced to conclude that the intrusives entered the shales through some channel not exposed.

AGE.

Intrusives in the Kennicott formation can not be older than the rocks into which they are intruded. Consequently they can not be older than late Jurassic or possibly early Cretaceous. No evidence bearing on their upper age limit was discovered in the Nizina district. It is perhaps true that the intrusions did not all take place at one time, and there might be cited as bearing on this point the fact that there is considerable variation in the composition and alteration of the intruded rocks. These two facts, however, are not in themselves proof. Such evidence as the intersection of one dike or sill by another dike or sill was not found, and it seems probable that the quartz porphyry intrusions belong to one period of intrusion.

Paige and Knopf have presented evidence to show that the quartz diorites of the Talkeetna Mountains are later than Middle Jurassic but younger than the late Jurassic, and state that they are "thus contemporaneous in a general way with that great series of batholithic intrusions of late Mesozoic age which affected the entire Cordilleran region from the Straits of Magellan to the Seward Peninsula of northwestern Alaska."[a] Quartz diorites of equivalent age intrude Upper Jurassic sediments in the Nutzotin Mountains northeast of the Wrangell Group.[b] There is a strong presumption that the quartz diorite porphyries of the Nizina district are but one manifestation of a disturbance that was widespread and of much greater importance in many other localities than it was here.

STRUCTURE.

Reference has already been made in the descriptions of the different formations to most of the structural features of the district, but for the sake of clearness these facts are here brought together in one section. Examination of the geologic map (Pl. III, in pocket) shows that in a general way the formations lie in zones extending in a northwest-southeast direction. Two sections are placed on the map to interpret the structure of these formations. They show that the prevailing dip of the formations below the Kennicott is toward the northeast but that the prevailing dip of the Kennicott itself is toward the southwest, and, further, that in consequence of the greater disturbances that have taken place in the older formations their general dip is considerably greater. Section *A–A* shows the synclinal structure of the Nikolai, Chitistone, and McCarthy formations along the northern boundary of the mapped area west of Nizina River. A parallel section northeast from any point on Dan Creek to Chitistone River or Glacier Creek would have shown this synclinal structure but with the syncline much flattened out, and a comparison of such a section with section *A–A* and the map would show that the synclinal axis pitches gently northwest. Section *A–A* also shows the unconformable relation of the Kennicott to the older formations, its comparatively low southwesterly dip, and the fault that here displaces the basal beds of the Kennicott and the Nikolai greenstone. Section

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[a] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: Bull. U. S. Geol. Survey No. 327, 1907, p. 20.

[b] Moffit, Fred H., and Knopf, Adolph, Mineral resources of the Nabesna-White district, Alaska: Bull. U. S. Geol. Survey No. 417, 1910.

B–B shows the Kennicott formation dipping gently to the southwest in broad open folds. The southwest dip is small but is sufficient to bring the interbedded shale and sandstone forming the upper part of the Kennicott formation well down on the slope of the mountains south of Young Creek, although these beds appear only on the tops of the high mountains south of Copper Creek and about the head of Rex Creek. At the northeastern end of this section the greenstone and the limestone lie almost horizontally, but a displacement has taken place by which the limestone is brought into contact with the black shale of the Kennicott formation, and it appears that near the fault plane the limestone dips to the southwest or toward the fault.

Faulting is of common occurrence in the Nizina district, but with the exception of the fault shown on the two sections most of the displacements are comparatively small in amount. The great fault just referred to is a strike fault—that is, its trend is the same as the prevailing strike of the formations and it extends from Copper Creek northwestward to McCarthy Creek. From work done in previous years it is known that this great fault continues westward beyond the Kennicott Glacier, but its course there has not been traced.

Good opportunities for studying the fault were found at two localities, one on the South Fork of Nikolai Creek and the other on Dan and Copper creeks. The north slope of the South Fork of Nikolai Creek is a dip slope formed by a thin veneer of basal Kennicott beds resting on greenstone. (See section *A–A*, Pl. III.) The south slope shows the basal Kennicott in the creek with a narrow belt of greenstone above it and above the greenstone a great thickness of Kennicott dipping to the southwest. The Kennicott and Nikolai formations in this locality were displaced by a fault in such a way that the rocks on the south side now have a relatively higher position than those on the north side. The fault dips high to the northeast and the displacement is about 800 feet. Very different conditions prevail on Dan and Copper creeks. Section *B–B*, Plate III, shows that the north slope of Dan Creek is formed of Nikolai greenstone and Chitistone limestone lying in a practically horizontal position. This condition does not hold on the south side; instead a great block of limestone abuts against black Kennicott shales and forms the point of the obtuse angle between Dan and Copper creeks. In this locality the displacement involves a raising of the north side relatively to the south side, exactly the reverse condition from that in the Nikolai Creek locality. This fault dips about 60° NE. on Dan Creek and, although complicated by minor cross faults, has a displacement that seems to be nearly or quite the thickness of the Chitistone limestone.

The same relative movement as that on Dan Creek took place on the two sides of the fault on the west side of Kennicott Glacier—that is, the formations on the north side were raised—yet no direct evidence was discovered to prove the existence of the fault between the glacier and McCarthy Creek.

Faults of this kind in which the relative movements of the two walls are opposite in direction at two different localities are known elsewhere, yet, inasmuch as the gravels of Nizina River prevent the demonstration that the Dan Creek fault is continuous with that of Nikolai Creek, it should be stated that the conditions described might result from the dropping of a block between two parallel faults, in which case we should be dealing not with one but rather with two faults. No evidence was seen in the field to raise a suspicion that two closely spaced faults occur here. A perpendicular fault almost parallel with the Dan Creek fault traverses the Young Creek valley, and a third, whose strike is more nearly east and west, crosses Nizina River a short distance north of the limits of the area mapped. The Young Creek fault is probably of the same order of magnitude as that of Dan Creek but is more difficult to study, since only one formation is concerned in the localities where it was examined. It has a known horizontal extension of 5 or 6 miles and the zone of disturbance is a wide one. These displacements, however, throw no light on the problems of Dan and Nikolai creeks.

The three faults just mentioned are the most prominent ones of the Nizina district, but they are not the only ones. There is evidence in many places of movement of the greenstone and limestone formations along their plane of contact, but measurements of displacement under such conditions are difficult. Undoubtedly faults are present in many places where they have not been recognized, for it is only under favorable conditions that they are discovered. Such conditions are provided by the limestone-greenstone contact. The character and frequency of faulting are shown on the geologic map by the contact north of Dan Creek. Displacements of the kind occurring there are difficult to recognize and to trace where only one of the formations is present. Most of the observed minor faults make obtuse angles approaching 90° with the major strike faults and are vertical or nearly so. They are present in many places and are commonly of small displacement in comparison with the strike faults even when of considerable horizontal extension. The shear zone of the Bonanza ore body is of this class. It was traced in a direction N. 30° E. from the mine for a distance of 1 mile, but the displacement at the limestone-greenstone contact is only 2 feet. A parallel fault on the east side of McCarthy Creek has a displacement of over 500 feet. The numerous faults north of Dan Creek are vertical or nearly so and have displacements ranging from 10 or 15 feet to several hundred feet. Minor strike faults were also noted, but since they do not cut bedding or formation boundaries they are apt to be undiscovered, as are also faults of low dip, such as the horizontal fracture planes of the Bonanza mine, along which slight movement has taken place.

In summarizing what has been said about faulting attention is directed to the fact that in a broad way the faults may be divided into two classes, those parallel to the prevailing strike of the formations and those that are approximately perpendicular to it. These may be referred to as strike faults and dip faults, for they are vertical or approximately so, and their strikes correspond in a measure with the direction of strike and dip of the formations.

The principal strike faults have given rise to great displacement of the rocks cut by them and persist for long distances horizontally. The dip faults are more numerous but the displacements are smaller. The effects of these faults on the rocks may be compared to the fracturing of the ice in a glacier. Blocks were formed which had to adjust themselves to surrounding conditions; some of them moved up, some down, as will be seen by examining the limestone-greenstone contact north of Dan Creek. In this way adjustments of great amount were brought about by many small, widely distributed displacements.

AREAL GEOLOGY.

The areal distribution of each formation has been indicated in the description of the formation. It now remains to bring these scattered facts together in one brief statement. Fully one-third of the mapped area is occupied by unconsolidated gravels, sands, etc., of glacial and fluvial origin (Pl. III, in pocket). Two-thirds of the remainder is given to the Kennicott formation. Consequently less than one-fourth remains to the rocks older than the Jurassic. The greenstone, the limestone, and the Triassic shales are confined strictly to a belt along the northeastern side of the area, but their territory is invaded in a few places by outliers of the overlying basal beds of the Kennicott formation. Triassic shales occupy only a small part of the area belonging to the older rocks, for the map does not extend far enough north to include the places of their greatest development. They are seen along the boundary of the mapped area between McCarthy Creek and Nizina River and in the vicinity of Copper Creek. The Nikolai greenstone and the Chitistone limestone form a narrow belt that extends northwest from Pyramid Peak to Kennicott Glacier. Nothing but Kennicott sediments and the igneous rocks intruded in them appears south of the Triassic formations. They appear in two principal areas on the two sides of Nizina River and are separated by a broad stretch of gravel deposits. Quartz diorite porphyries cut the Kennicott sediments in all parts of the district but find their greatest development in the black shales, particularly the shale area north of Nizina River. The porphyry sills of Copper Creek are conspicuous because of their persistence, but the intrusives of Porphyry and Sourdough peaks are so much greater in amount that they dominate in the upper parts of these mountains.

It may not be out of place to state here that the four formations of the Nizina region continue northwestward beyond Kennicott Glacier and that their areal relations there are practically the same as on the east side. Black Kennicott shales with numerous porphyry intrusives make up the mountains west of Porphyry Peak on the opposite side of Kennicott River, and the greenstone and Triassic sedimentary formations appear north of Fourth of July Pass. The mountain in the middle of the glacier, known as "The Peninsula," gives an excellent section of the greenstone and the two Triassic formations. Greenstone forms the southern point of "The Peninsula." On it lies the northeastward-dipping limestone, which is succeeded in turn by the Triassic shales. This locality is one of a few in this region where the limestone has been closely folded and much contorted.

It is known regarding the extension of these formations toward the southeast that the greenstone outcrops on Canyon Creek east of Young Creek, and it is probable that both greenstone and limestone extend still farther eastward into the Chitina Valley. Schrader traced the black Jurassic shales, which were at first thought to be Triassic, as far east as Canyon Creek, but beyond that there is no information concerning them.

HISTORICAL GEOLOGY.

SEDIMENTARY AND IGNEOUS RECORD.

In describing the formations of the Nizina district the rocks of sedimentary origin were considered in one group and those of igneous origin in a second. This treatment by family groups is not followed in the discussion of the historical geology of the district, but rather it is attempted to give in the order of their occurrence the geologic events connected with the different rocks.

The first event in the geologic history of the district concerning which we have evidence within the district is the outpouring of lavas that are now known as the Nikolai greenstone. This took place previous to the deposition of the Chitistone limestone, and consequently either in Upper Triassic time or in some period preceding it. It is not, probable, however, that the greenstone flows are older than the Triassic, since the best evidence at hand indicates that they are later than Carboniferous. The flows did not take place as a single event but were doubtless continued through a considerable time interval. There is some reason to believe that they may have been poured out under water, although it is by no means established that such is the case; yet, whether they accumulated in the sea or whether they accumulated on land and were later carried below sea level by subsidence of the land, the beginning of deposition of Upper Triassic marked the complete cessation of volcanic activity for the time being. Deposition of the Chitistone limestone continued for a long interval of time without important changes in the character of the material laid down. At first the conditions of accumulation were relatively stable and the massive beds at the base of the Chitistone were formed, but later conditions changed, for the beds grew thinner, and finally thin partings of shale began to appear. The commencement of shale deposition marked the beginning of the transition from the Chitistone limestone to the McCarthy shale. As the shale beds increased in amount the limestone decreased, till finally shale predominated and limestone was no longer of importance in the formation. All these events that concern the sedimentary formations took place before the end of the Triassic period. They terminated with an elevation of the Triassic sediments above sea level, which was accompanied or followed by deformation and folding of all the sedimentary beds and the greenstone. Erosion of the new land surface began as soon as elevation took place and, unless part of the historic record has been lost or overlooked, continued throughout Lower and Middle Jurassic time. During this erosion period an enormous quantity of material was removed from the land and returned to the sea, but what became of it is not known. The beveled edges of the greenstone, the limestone, and the shale bear evidence of an areal extension of these formations beyond the limits now recognized and testify to the thousands of feet of material carried away.

Erosion was at last interrupted by the advance of the Jurassic sea. This advance probably took place from the west, where it began in Lower Jurassic time, as is known from the presence of Lower Jurassic beds on Cook Inlet. Upper Jurassic sea prevailed in the Chitina region long enough to permit many thousand feet of sediments to accumulate. This sea is supposed to have been a somewhat restricted one. The waters were shallow. Probably a land mass existed to the south in the region of the present Chugach Mountains and separated the sea from the ocean. The sediments deposited in the Jurassic sea are not all of one kind and were deposited under varying conditions. The Kennicott formation bears within itself evidence of many and important changes during the time when it was being laid down. Shore conditions are indicated by the basal conglomerate, but the gradual upward decrease in size of the pebbles that form the conglomerate and the transition from conglomerate or grit to sandstone and from sandstone to fine black shales tell of a progressive change in conditions that is difficult to interpret, for it may have been caused in various ways. The great thickness of fine black shale, however, is evidence of long-continued stability in the source of supply and the manner of deposition of the materials composing them. Stability at last gave place to instability, and another great thickness of interbedded shales and sandstones followed the black shales till the last known event of Upper Jurassic deposition took place and the massive upper conglomerate was laid down. Deformation, elevation above sea level, and intrusion by quartz diorite porphyry are the next events recorded in the rocks of the mapped area, and they lead up nearly to the beginning of development of the present topography. Yet there is reason for assuming that the Kennicott formation does not represent the latest rocks of the Nizina district and that other younger sedimentary and igneous rocks may have once been present but are now entirely removed. This assumption is based on the presence of coal-bearing beds and still younger lava flows in the vicinity of Fourth of July Creek, west of Kennicott Glacier, and on the head of Chitistone River. Neither of these localities has been studied in detail. The coal of Fourth of July Creek is confined to a small area. It lies horizontally, is associated with black carbonaceous shale, and is overlain by arkose sandstone and an andesitic lava flow. Its relation to the great fault that cuts the Kennicott and older formations is such as to leave little doubt that it was deposited after faulting took place, and it is provisionally referred to the Tertiary. Coals associated with shales and sandstones and overlain by lava flows are exposed on Chitistone River. These beds also are referred to the Tertiary. The presence of these younger rocks in the immediate vicinity makes it appear highly probable that they may have extended into the region under consideration, since it is difficult to understand how they could have been deposited where they now appear without being much more widespread than they are. A coal-bearing formation consisting predominantly of coarse arkose and showing no evidence of marine conditions, but included between marine Tertiary formations, reaches a thickness of more than 2,000 feet in the Controller Bay region.[a]

More than 3,000 feet of fresh-water coal-bearing Tertiary sediments are exposed in the Matanuska region.[b]

These sediments comprise "a series of sandstones, shales, arkose, numerous coal seams, and a large volume of conglomerate." The Gakona formation of the Copper River basin[c] is a coal-bearing formation of fresh-water origin. It reaches a thickness estimated to be not less than 2,000 feet and includes 500 feet of conglomerate, together with shale, gravel, sand, and lignite beds. Other areas of supposedly Tertiary sediments appear in the Copper River valley, but very little is known about them. If the coal-bearing rocks occurring just north of the Nizina district are of Tertiary age, it is a reasonable presumption in the absence of definite proof that they, like the coal-bearing Tertiary formations of the Matanuska and Copper River basins, are of fresh-water origin, and that therefore there is no necessity for assuming a submergence of the region below sea level after the Kennicott formation was deposited. The element of doubt in this presumption lies in the uncertainty concerning the age of the coal, for it is known that the Upper Jurassic formations as well as the Tertiary formations of the Matanuska region carry coal.

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[a] Martin, G. C., Geology and mineral resources of the Controller Bay region, Alaska: Bull. U. S. Geol. Survey No. 335, 1908, p. 31.

[b] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: Bull. U. S. Geol. Survey No. 327, 1907, p. 27.

[c] Mendenhall, Walter C., Geology of the central Copper River region: Prof. Paper U. S. Geol. Survey No. 41, 1905, p. 52.

PHYSIOGRAPHIC RECORD.

There is good evidence in many parts of Alaska to show that at the time when the Tertiary coal formations were deposited the land had a much lower relief than it has to-day. The present mountain ranges, although perhaps distinctly outlined, had not yet reached their full development. The coal formations were laid down in depressions of a land surface that must have lacked in large measure the rugged character that we now see. Probably this land surface presented many of the features of the present Copper River or Yukon valleys in their broader parts. Such appear to have been the conditions when the forces that resulted in the uplifting production of the present Chugach Mountains and the Alaska Range began to be felt. These forces doubtless acted slowly, but they acted for a long period of time, and they may be in operation yet. They brought about the uplift of the mountain areas and made it possible for the agents of erosion to initiate the work of forming the present mountain and valley features. They were accompanied by or were the cause of the extrusion of a great volume of lava that has continued almost to the present day and is the most characteristic feature of the Wrangell Mountains, the feature that distinguishes them from the Chugach Mountains on the south and the Alaska Range on the north.

Chitina Valley is a very old topographic feature and was formed by a stream that probably had an outlet by way of the upper Copper River valley either into the drainage basin of Cook Inlet or possibly into the Yukon Valley. Its axis coincides with the boundary line between the older metamorphic rocks of the Chugach Mountains and the younger, less-altered rocks on the north side of the valley. This boundary in part marks an unconformity of deposition and possibly also one of faulting, but in either case it appears to have been a determining factor in locating the position of the valley. The valleys of Nizina River and the other streams of the Nizina district, like the Chitina Valley, originally represented the work of streams alone and were the result of normal stream erosion, but they have been profoundly modified by the action of glacial ice. This modification is represented chiefly by changes in valley forms due to straightening of the sides, alterations in the form of cross section, and lowering of the valley floors, together with changes brought about by the deposition of unconsolidated glacial materials. These modifications having already been described in the section on glaciation, it is unnecessary to repeat their description here. It is only necessary to say that the most conspicuous topographic features we see to-day owe their present appearance to recent glaciation, yet that subsequent stream cutting and rapid subaerial erosion due to the subarctic conditions have begun to modify the land forms left by the retreating ice. These later features are seen in the rock-walled canyons on the lower courses of all the streams, the deep gulches such as cut the Kennicott formation on White and Young creeks, and the great accumulations of loose material in the form of talus.

ECONOMIC GEOLOGY.

HISTORY.

The history of mining in the Chitina Valley begins with the rush of prospectors to Valdez in 1898. These men were influenced by the gold discoveries in the Yukon Basin during the preceding two years and came to Valdez in the hope of finding an easier route to the Yukon or new placers in the Copper River valley. Reports of copper on Copper River had circulated since the time of the Russians, who found in the hands of natives copper that probably came from the Nizina district, yet a majority of the prospectors were in search of gold, not copper. A few, however, turned their attention to copper and crossed from Valdez to the Wrangell Mountains, where their efforts received encouragement. In the following year (1899) the search for valuable minerals was resumed and prospecting parties ascended Chitina Valley as far as the Nizina district. It is doubtful if they attempted to go farther east in the main valley, and for that matter there has been little effort to prospect the upper Chitina region in the years since then. The Nikolai copper lode was shown to a party of white men by a native sent for this purpose by Chief Nikolai, of Taral, in July, 1899. Nikolai's house was at the mouth of Dan Creek, and the ore body was doubtless discovered by the natives on some of their hunting expeditions. It is usually difficult to reconcile the statements of different persons concerning the early events connected with the history of a new country, and the Nizina district is no exception to the rule. It is said that gold was discovered on both Dan and Young creeks at about this time, but either the quantity found was small or the difficulties met prevented any immediate steps toward developing the property.

Work was begun on the Nikolai mine in 1900 for the purpose of securing a patent to the claim. Some of the men who were interested in the property devoted part of their time to further prospecting, and in this way the large body of chalcocite named the Bonanza ore body was discovered about the end of July or the first of August (1900) by C. L. Warner and Jack Smith. It was discovered independently a short time later by Spencer, of the United States Geological Survey, who was engaged in mapping the contact of the Nikolai greenstone and the Chitistone limestone. Up to this time interest in gold placers had been secondary to that in copper prospects, but the presence of gold on Dan Creek was not forgotten, and in 1901 the creek was staked by C. L. Warner and D. L. Kain for themselves and others. Mr. Kain was known to his companion as "Dan," and they named the creek after him.

The first men to find gold on Chititu Creek were Frank Kernan and Charles Koppus, who came to the creek in the first part of April, 1902. They were joined shortly afterwards by two others, Messrs. Rowland and Dimmet, and these men staked the creek for themselves and their partners on April 25. News of the Nizina strike quickly reached the outside, and by July of 1902 the stampede was under way. A new town sprang up on Chititu Creek and was quickly provided with all the usual elements of a thriving placer camp, but there was not enough placer ground to support all comers, and most of the population soon vanished. The richest and most easily mined gravels were largely worked out in the first years by pick and shovel, but since that time the claims on both Chititu and Dan creeks have become more and more consolidated in the hands of a few owners, who are preparing to handle their gold-bearing gravels on a larger scale by more economical methods.

A similar consolidation of ownership has taken place in the case of the Bonanza mine, so that now instead of 11 principal ownerships, some of them representing two or more persons, the property is controlled by a single strong corporation capable of supplying the large capital necessary to develop the ore body.

The mineral production of the Chitina Valley to the present time consists entirely of gold, which is practically all from Chititu and Dan creeks. Copper has not been produced in a commercial way because there is no means of getting it to the coast, so that all the copper brought out is that taken for samples and assays.

COPPER.

OCCURRENCE OF THE ORES.

GENERAL STATEMENT.

An examination of the copper prospects of the Chitina Valley was made by members of the United States Geological Survey in 1907, and a report of that work was published in bulletin form later.[a]

Since that time there has been considerable advancement in the development of some properties and a few discoveries have been made, yet the results of the work done have thrown no light on the nature of the changes which take place in the ore bodies as distance from the surface increases. This question, excepting that of the amount of ore present, is probably the most important one concerning the copper deposits of the region. A study of the copper deposits on the eastern side of the Wrangell Mountains[b] has shown that copper occurs there under much the same conditions as in the Chitina Valley and has suggested some further ideas as to the origin of the ores. The descriptions and discussion that follow, then, are based partly on previous work but have received such revision and addition as have been found to be necessary.

Copper ores in the Chitina Valley north of the river occur in three ways—as copper and copper-iron sulphides associated with the Nikolai greenstone and with the Chitistone limestone; as native copper associated with the greenstone; as placer copper accompanied by native silver and gold. The important copper minerals are chalcocite or copper glance, bornite, chalcopyrite, and native copper. In every copper prospect there is a small quantity of one or more of the oxidation products, such as green malachite stain, azurite, and less frequently the red oxide, cuprite. Chalcanthite, or blue copper sulphate, and the black oxide, tenorite, are rare. Covellite is associated with chalcocite in some localities.

The ore bodies occur as replacements of greenstone or of limestone or as fillings in cavities developed along fault planes, shear zones, or joint planes in greenstone or limestone. A few examples are known of ore bodies to which the term "fissure vein" might be applied in its popular sense, but by far the greater number of the copper deposits are aggregates of copper minerals forming ore bodies of irregular shape which are well described by the term "bunch deposits," yet even the "bunch deposits" are believed to owe their existence to the presence of faults or fractures that permitted the circulation of copper-bearing solutions. Aggregates of copper minerals are far more common in the greenstone than in the limestone, but the largest deposits that have been discovered up to the present are in limestone. Most of the deposits in limestone are near the base of the Chitistone formation, yet there are a few notable exceptions to this general rule. On the other hand, the attempt to show that deposits in the greenstone are most apt to occur near or at the limestone-greenstone contact was not successful, and the field evidence seems to indicate that copper occurs in nearly all parts of the formation and that the location of ore bodies is dependent only on favorable conditions of supply or for deposition.

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[a] Moffit, Fred H., and Maddren, A. G., Mineral resources of the Kotsina-Chitina region, Alaska: Bull. U. S. Geol. Survey No. 374, 1909.

[b] Moffit, Fred H., and Knopf, Adolph, Mineral resources of the Nabesna-White district, Alaska: Bull. U. S. Geol. Survey No. 417, 1910.

COPPER SULPHIDE DEPOSITS IN GREENSTONE AND LIMESTONE.

Although this part of this paper is intended to deal only with the copper prospects of the Nizina district, it is necessary in the description of the ores to consider the district in its relation to the rest of the Chitina region. The best examples of copper sulphides in greenstone are not found within the region under consideration but to the west of it. The copper minerals are bornite, chalcopyrite, and chalcocite, with secondary alteration products, and they occur (1) in irregularly shaped ore bodies without any conspicuous amount of associated gangue minerals or (2) as well-defined veins accompanied by a gangue of calcite and quartz. Ore bodies of the first kind occur in shear zones or in jointed or shattered portions of the rock. The copper minerals fill fractures in the rock, or more commonly they replace the rock itself. Bornite and chalcopyrite are of more common occurrence than chalcocite, yet some of the most promising ore bodies in the greenstone consist chiefly of chalcocite.

A careful examination of the many copper prospects leads to the belief that most of the ore bodies are of the "bunch deposit" type and are a replacement of the greenstone by copper minerals carried in solutions that circulated along fracture planes produced by jointing, shearing, or faulting of the country rock. The mineralized parts of the greenstone are without definite boundaries in many places, and the ore grades from solid sulphides to disseminated grains or particles scattered through the greenstone, which grow fewer and fewer as distance from the fractures increases till they disappear altogether. Sections of ore examined under the microscope show that the two sulphides bornite and chalcopyrite are closely associated and are intermingled in such a way as to suggest that they were deposited at the same time. Chalcopyrite is practically always present, even in ore that appears to the naked eye as pure bornite. Chalcocite accompanies the bornite and chalcopyrite in some specimens, and the association is such as to suggest that the chalcocite was derived from the poorer sulphides, but this was not definitely proved. A few of the deposits in greenstone consist entirely of chalcocite.

The vein deposits accompanied by gangue minerals are associated with well-defined faults in all the best examples. The copper minerals are bornite and chalcopyrite, and the gangue is chiefly calcite accompanied by quartz. Epidote is commonly present also. The veins pinch and swell markedly in short distances and in all the localities where they were examined have been subjected to faulting or other movement since their deposition.

Copper deposits in limestone were formed by replacement of the limestone as a whole by copper minerals in solutions circulating along fracture planes such as faults, shear zones, or joints. The copper minerals are chalcocite and bornite, accompanied by malachite, azurite, and in places covellite as alteration products. As a rule, the boundary between ore and country rock is distinct, although the form of the ore body itself may be very irregular. This is particularly true where the copper mineral is chalcocite. In deposits of bornite in limestone a dissemination of the copper mineral through the adjacent country rock was noticed, and in such examples there is a gradation from ore to country rock similar to that in the greenstone deposits. One of the best examples of this kind shows a large proportion of chalcocite associated with the bornite, and the deposition of the copper was accompanied by a thorough silicification of the limestone. Large masses of chalcocite like that of the Bonanza property are distinctly replacement deposits in fracture zones. No fragments of limestone are included in the body of the ore, although isolated masses of chalcocite are scattered through the limestone. The ores are most frequent near the limestone-greenstone contact, yet some of them must be fully 1,000 feet above the base of the limestone. It is a notable fact that azurite is far more common as a secondary oxidation product in the limestone replacement deposits than malachite and that it is not common in the deposits in greenstone. Small veins of azurite with cores of chalcocite show distinctly that the azurite in the Bonanza mine was produced by the alteration of chalcocite. Covellite originated in a similar manner.

NATIVE COPPER ASSOCIATED WITH THE GREENSTONE.

Native copper is associated with amygdaloidal phases of the Nikolai greenstone and is also found accompanied by quartz or by quartz and epidote in veins cutting the greenstone. Most commonly it occurs as grains and small slugs in the amygdules and disseminated through the greenstone and as films or leaves and small veinlets cutting the greenstone. Tabular masses deposited in joint planes without much doubt indicate the way in which the large masses of native copper and the copper nuggets in the Dan and Chititu placers were formed. Such masses found in place on the head of White River are believed to have resulted from the alteration of chalcocite. In a few places in the tributary valleys of the Chitistone and Kotsina rivers native copper occurs in amygdaloidal greenstone in association with a mixture of copper oxide and carbonaceous matter, filling vesicles and fractures in the lavas. Such native copper as is known in the Nizina district is probably due to the reduction of previously formed sulphides or oxides, yet primary native copper is known on the head of White River. There is a strong similarity between the native copper-bearing greenstone of Chitina Valley and the amygdaloidal copper ores of Lake Superior. Specimens from the two regions could be selected between which it is doubtful if close observation could distinguish. This similarity would also extend to the disseminated sulphide ores in greenstone if by any means the sulphides could be altered to native copper.

PLACER COPPER.

Native copper is associated with silver and gold in the gravels of Chititu and Dan creeks. It occurs in pieces that range in size from fine shot to masses weighing several hundred pounds. Two or three tubs of fine copper are secured at each "clean-up" of the sluice boxes on Chititu Creek and give much difficulty in cleaning the gold, since the finest of the copper has to be removed by hand. Many of the nuggets contain native silver, which shows that the copper and silver are here closely associated in origin. The remarkable similarity in form and appearance between the copper nuggets of the Nizina district and the larger masses of copper taken from the stamp mills of the Lake Superior region is evident to anyone who compares the two, since the chief differences are that the placer copper has a slightly smoother surface and an oxidized coating. The copper and silver are derived wholly or in part from the greenstone. Assays of chalcocite from the Bonanza mine and from other copper ores of the Nizina district have shown the presence of both silver and gold in the copper deposits. Small particles of native silver were found in a freshly broken specimen of greenstone from a bowlder on Chititu Creek, and an assay of the rock also showed its presence. The silver was associated with calcite in small fractures. Silver nuggets up to 7 pounds in weight have been found on Dan and Chititu creeks, but where silver is associated with copper in the same nugget copper predominates, and in general silver is seen only as small particles in the copper. Copper is found only in those tributaries of Dan and Chititu creeks where greenstone pebbles and bowlders form part of the stream gravels; consequently it occurs only where the gravels have been formed in part by streams flowing through greenstone areas or where there is a foreign element in the gravels that was derived from a greenstone area and brought to its present position by glacial ice.

ORIGIN OF THE COPPER DEPOSITS.

It is not yet possible to give a satisfactory account of the origin of the copper deposits, but some features of their history can be stated with a considerable degree of certainty, and it is desirable to do this, since it may be of value in future development work. A history of the present deposits is concerned chiefly with three problems--the source of the copper minerals, the manner in which they were brought to their present position and deposited, and the changes that have taken place in them since they were deposited.

It is believed that the source of the copper is within the Nikolai greenstone itself and that only a very small part, if any, is derived from an outside source. The chief argument in favor of this view is the widespread and almost universal occurrence of copper minerals in the greenstone wherever it is exposed. This is seen in hundreds of places in all parts of the formation, from the west end of the Chitina Valley to Nizina River and the upper Chitina. Wherever fractures in the greenstone have permitted water to circulate the green copper stain is apt to be found. Probably the copper was originally present in the form of sulphide in the lava flows, but this does not exclude the possibility of its also having been combined in other minerals of the rock. Pyrite and chalcopyrite are of common occurrence in the greenstone, as is proved by both the hand specimens and the thin sections examined under the microscope. This source is believed to be adequate for supplying all the copper concentrated in the present ore bodies.

An examination of the greenstone in many places has shown that considerable chemical alteration in its constituent minerals is universal. No fresh and unaltered specimens of the rock were found. Alteration began first and is greatest in the pyroxene, and in many places this alteration is complete, so that there now remains only a mass of chloritic or serpentinous material. The feldspar has suffered less, yet the changes are advanced. Opaque masses of brown iron oxide appear to represent original grains or crystals of pyrite or chalcopyrite. These changes have resulted in the production of chloritic and possibly serpentinous material, calcite, quartz, and delessite. In places zeolites as thomsonite have been produced, but they are comparatively rare in the Nizina district and the region to the west, although they are abundant in amygdaloids of the White River region.

Changes of the kind mentioned are usually considered to be accomplished through the agency of circulating water. Chemical changes in the minerals of the basalts were made possible by the presence of water and the substances carried in solution. By the same means copper minerals were taken into solution and redeposited under favorable conditions. It is a noteworthy fact that the Wrangell Mountain region has been one of volcanic activity since Carboniferous time at least, and, although it has not been possible to establish a direct relation between the copper deposits and any igneous rocks of later age than the Nikolai greenstone, it is not unreasonable to suppose that the presence of heated rocks in the near vicinity may have had an important influence in promoting circulation in the greenstone and particularly in increasing the solvent power of the circulating water.

As to the manner of deposition, it is believed that the copper taken into solution by circulating water was carried into trunk channels and deposited there when the conditions were favorable. Speculations as to the exact chemical changes that took place are of very doubtful value with the present knowledge of the facts and will not be attempted. Most frequently deposition took place in the greenstone formation, but at times the copper-bearing waters passed outside the greenstone and into the overlying limestone before giving up their mineral load. As a rule, the ore bodies were not formed by the deposition of copper minerals in open cavities, although openings sufficient to permit a circulation of water were necessarily present. Most of the ore is a replacement of the country rock itself by copper sulphides. The replacement of greenstone is more nearly complete adjacent to the openings through which water passed and grows less and less as the distance from the openings increases. On the other hand, most of the limestone ores show a complete replacement of the limestone without any outside zone of disseminated sulphides.

Examination with the microscope has shown that bornite and chalcopyrite are usually associated in the greenstone deposits, even in bornite ores that show no chalcopyrite to the unaided eye. This fact, together with the manner in which chalcopyrite is scattered through the bornite, might be taken as presumptive evidence that the bornite was derived from chalcopyrite and is a secondary enrichment. This fact alone does not amount to proof, but the seeming increase in chalcopyrite as depth is gained in some of the bornite-chalcopyrite veins, such as the Nikolai vein, lends some weight to the presumption. The presence of native copper associated with chalcocite and bornite also points to the same conclusion, since native copper is usually regarded as of secondary origin. On the other hand, no evidence was found in the chalcocite deposits in limestone, such as that of the Bonanza mine, to indicate that the ore body has ever been anything other than what it is at present. The copper sulphide appears to have been deposited as such, and a careful examination of the ore has failed to discover the presence of other minerals than those produced by alteration of the chalcocite. It is doubtful if secondary enriched ores could form under the conditions now prevailing at the Bonanza mine, since all openings such as are due to joints and other fractures are filled with ice, as is also the loose talus material below the mine on both sides of the ridge. Furthermore, the breaking down of the ore and of the limestone inclosing the ore body under the climatic conditions of this region proceeds faster than oxidation. The exposed ore on the ridge and loose broken-down ore on the talus slopes show only a thin film of oxidized material on the surface. Yet thin veins of chalcocite in the limestone and even large masses of chalcocite have been almost completely altered to azurite, which shows that oxidation has taken place either under present conditions or, more probably, under earlier and more favorable conditions, possibly before the late ice advance.

The ore of the Westover claim, on Dan Creek, is an intimate mixture of chalcocite and bornite in silicified limestone along a fracture zone. The copper and copper-iron sulphides are disseminated through the rock in small grains and in veinlets cutting the rock. Most of the disseminated grains are chalcocite, but the veinlets and the larger irregular masses are a mixture of chalcocite and bornite. The veinlets are later than the quartz inclosing them and possibly later than the disseminated grains in the quartz, yet the minerals of the veinlets appear to be contemporaneous. These examples show how unsatisfactory is the evidence concerning the nature of the deposits, but they have some importance in that they do not promise greater richness in copper as the ores are followed below the surface. This point is emphasized because of the belief on the part of many prospectors in the Chitina region that the deposits will grow richer as they are more fully developed. The contrary is more likely to be true, for although they may continue with their present richness they are more apt to grow poorer than to grow richer.

DESCRIPTION OF PROPERTIES.

PRINCIPAL GROUPS.

The better-known copper properties of the Nizina district may be divided into three groups—first, the group in the vicinity of Bonanza Peak, including the Bonanza mine, the Jumbo, the Erie, and the Independence claims, together with the properties known as the Marvellous and Bonanza extension claims; second, the Nikolai Creek group; and, third, the group that includes the Westover claim and other neighboring claims north of Dan Creek. Many other claims have been staked, particularly along the limestone-greenstone contact, but there has been little development work done on them and they contribute little to our knowledge of the copper deposits of the district.

BONANZA MINE.

The Bonanza mine is the most valuable[a] copper property now known in the Copper River region. It is situated on the east side of Kennicott Glacier, at the head of Bonanza Creek, and is the property of the Kennicott Mines Company. Bonanza Creek proper and its western fork head in a glacial cirque basin on the west side of the high divide between Kennicott Glacier and McCarthy Creek. Its two forks include the high ridge on which the copper deposit is situated. The stream is about 3 miles long and flows in a southwesterly direction to the Kennicott Glacier. A post-office called Kennicott has been established at the mouth of National Creek, half a mile south of the mouth of Bonanza Creek and 4 miles from the mine, and the company's main camp and office are located at that place. A wagon road leads from the mouth of National Creek to a point about 500 feet below the mine and another follows the edge of the glacier south to McCarthy Creek. An aerial tram with a capacity of 100 tons per day has been constructed and loading and delivery stations have been built, so that the mine is now practically ready to begin the production of ore, although the storage bunkers are not completed and no ore can be shipped till the railroad reaches Kennicott.

An examination of the geologic map (Pl. III, in pocket) will make clear the general geologic conditions. South of National Creek the high ridge between the glacier and McCarthy Creek consists of black Kennicott shale intruded by large masses of light-gray porphyry. The Jurassic shales and intrusives are separated by an unconformity and probably also by a fault from the greenstone and the overlying Chitistone limestone on the north. North of National Creek the greenstone and limestone appear. The strike of the limestone is northwest and southeast, and its dip averages between 25° and 35° NE. It therefore cuts diagonally across the main ridge from McCarthy Creek to the glacier. Still farther northeast the Triassic shales overlying the limestone appear, but are not of any importance in connection with the copper.

The Bonanza mine is situated on a spur that runs out to the southwest between the forks of Bonanza Creek from the main ridge. This spur is crossed by the limestone-greenstone contact at a point about one-third of a mile from the main ridge. Where the boundary crosses the crest of this spur it has an elevation of 6,000 feet above sea level or 4,000 feet above the point at the mouth of National Creek where the tramway will deliver ore. On the northeast the spur

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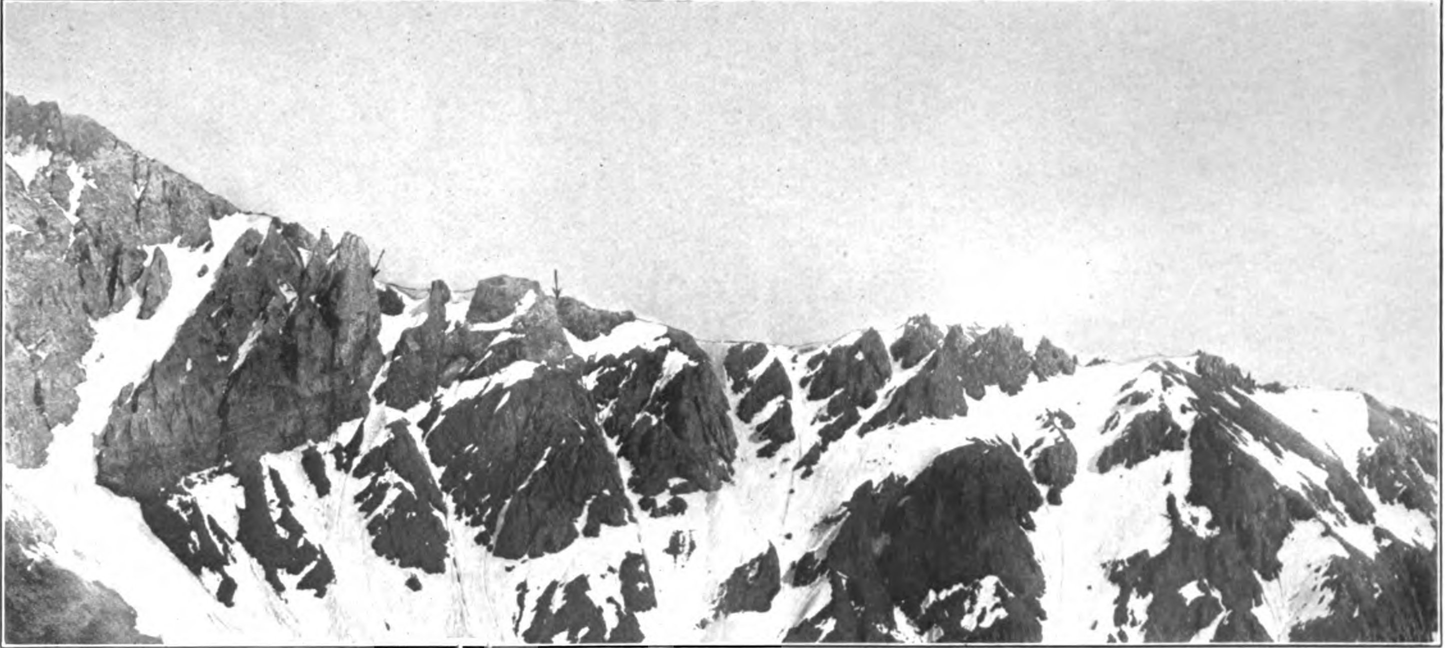
[a] Since the Bonanza mine was visited in 1907 much work has been done toward surface development and equipment of the mine for shipping ore, but work on the ore body itself has not been such as to add greatly to the knowledge of the deposit. For this reason the description here given is based largely on the previous description published in Bull. U. S. Geol. Survey No. 374.



U OF M

WEST SIDE OF RIDGE AT BONANZA MINE.

The richest ore exposed on the surface is on the top and face of the ridge between the points indicated by arrows. See page 85.

U of M

rises rapidly till 1,000 feet in elevation is gained, but on the southwest its crest is almost horizontal for a distance of about one-third of a mile, beyond which it slopes away steeply to the forks of Bonanza Creek (Pl. XII).

The greenstone immediately below the ore body is variable in texture and general appearance. Part of it is amygdaloidal; porphyritic phases are also present. Amygdules are not confined to the top of the flows but are present throughout from bottom to top. In some places they have been dissolved out on exposed surfaces, leaving a vesicular rock that looks like a recent lava. A bed of red and green shale having a thickness of about 5 feet intervenes between the greenstone and the overlying limestone. This shale forms a narrow northward-sloping bench for a short distance along the northwest side of the ridge, but is everywhere covered with talus and is found only when the débris has been cleared away. The bench is clearly indicated by the snow banks in Plate XII. The base of the limestone consists of not less than 40 feet of coarse gray, slightly argillaceous rock, whose broken surfaces are covered in many places with flattened cylindrical bodies that immediately suggest organic material of some kind. Several specimens of these bodies were submitted to Dr. T. W. Stanton, who says that they are probably corals but are too obscure for identification. Over this basal limestone is a bed a few feet thick of impure shaly limestone, and this in turn is overlain by dark and light-gray massive beds which carry the ore bodies. The limestone dip at the mine is slightly variable but averages about 22° NE.

The limestone is broken by numerous faults and fracture planes, the most prominent of which are nearly perpendicular and range in strike from N. 40° E. to N. 70° E. A minor set of fault planes with about the same strike dips steeply to the west. Another set runs in a northwesterly direction, and in several places striations on slickensided surfaces or clay seams show that the movement was horizontal. Fault planes with low dips, some of them nearly horizontal, are also present. None of the faults observed give evidence of much displacement, but together with the numerous joints they afforded an opportunity for mineral-bearing waters to enter the limestone. The principal fault planes—those running from northeast to southwest—form what may be described as a sheeted zone in the limestone that was traced north-northeast from the Bonanza mine for 1½ miles. This zone has a width of 50 or 60 feet and extends through the shale bed into the greenstone below, but is less noticeable in the greenstone than in the limestone. A vertical displacement of 2 feet occurs in the limestone-greenstone contact along one of the fault planes in the shear zone and is the maximum displacement observed.

The copper ore is chalcocite. Considerable azurite has been formed by oxidation of the chalcocite, and covellite is reported also. Covellite was not found in the specimens of ore collected from the Bonanza mine by the writers, but good specimens of covellite were collected from the Marvellous claim half a mile to the northeast, and its occurrence at the Bonanza is not questioned. The chalcocite is in veins or tabular masses of solid ore up to 5 or 6 feet in thickness, in large irregularly shaped bodies, and in stockworks in the brecciated limestone. Two principal veins of chalcocite are seen on the surface. They stand almost perpendicularly, 12 to 15 feet apart, and strike N. 41° E., forming the comb of the sharp ridge but crossing it at a slight angle, as the ridge at this place has a more nearly north-south direction than the veins. On the surface the veins do not extend down into the lower impure part of the limestone but end abruptly on reaching it. In places the precipitous northwest face of the ridge is plastered over with masses of solid chalcocite for a distance of 50 or 60 feet vertically below the top.

Azurite appears on the surface of the chalcocite and also as a lining of small vugs in the chalcocite, but it is present chiefly as thin veins, that form a network in the limestone and are doubtless due to the alteration of original chalcocite veins, for some of the azurite has an inner core of chalcocite. Azurite is more conspicuous than chalcocite in the surface network of veins in the northern 150 feet of the ore body, but chalcocite forms the great mass of the remainder. The ore bodies formed along the northeast-southwest faults of the northern part of the deposit are not the direct continuation of the large chalcocite veins at the south, but lie in nearly parallel veins which cut the ridge at a greater angle, their strike being about N. 60° to 70° E. The very rich ore can be traced on the surface for a distance of about 250 feet. It ends abruptly on the south in a nearly vertical limestone wall, but on the north gives place to the lower-grade ores, consisting of small veins of azurite and chalcocite with scattered masses of chalcocite, some of them weighing several tons. This lower-grade ore shows on the surface for a distance of at least 150 feet northeast from the high-grade ores, and small scattered azurite veins extend still farther in that direction. The ore, as it shows on the surface, therefore, extends northeast and southwest along the strike for a distance of 400 feet. The thickness, however, is more indefinite, but the very rich ore, with its included limestone, as seen at the surface, has a width of approximately 25 feet, although the thickness of ore sufficiently rich to be mined may be greater.

A little chalcocite and less bornite are found in some of the shearing planes in the greenstone, but they do not extend far into the greenstone. The quantity is small and inconspicuous and might readily pass unobserved. A small amount of epidote is associated with it in places. The main shear zone in the greenstone cuts an older set of quartz-epidote veins whose direction is about north-northwest. These veins do not intersect the limestone. They reach a maximum thickness of 1 foot and carry small amounts of chalcocite, bornite, and native copper.

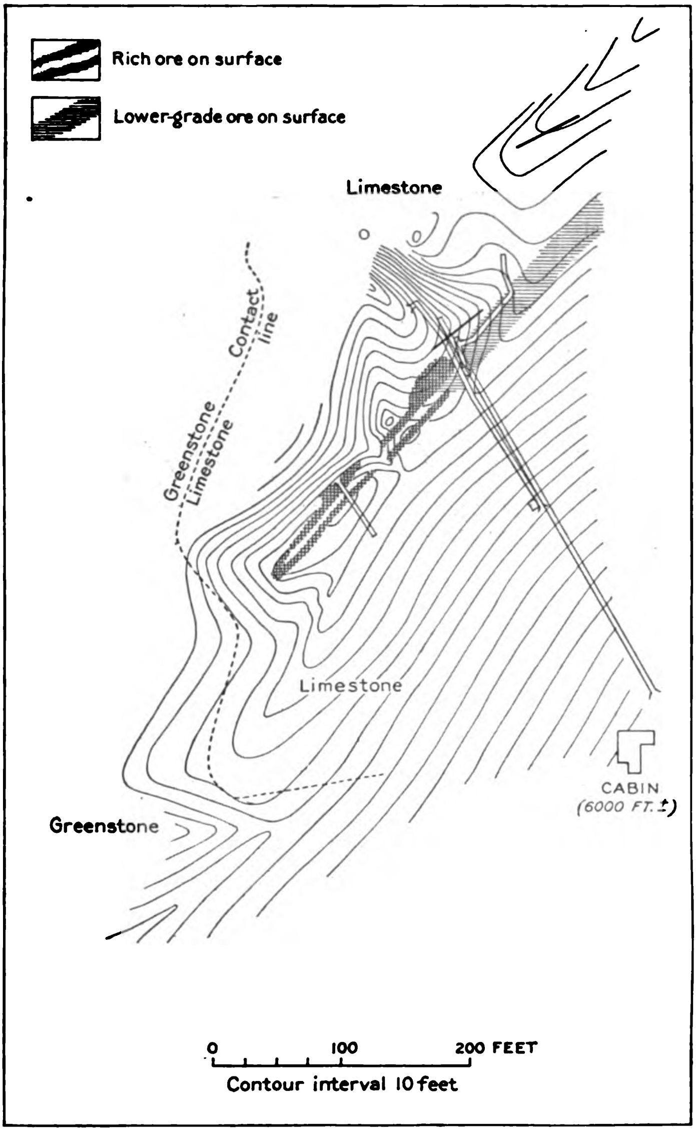


FIGURE 5.—Sketch map of the area near the Bonanza mine, showing the limestone-greenstone contact, the location of the richer ores on the surface, and the tunnels.

When the Bonanza mine was visited in 1907 two crosscuts (fig. 5) had been driven in the ore body in a direction N. 33° W. They are therefore not exactly perpendicular to it. The longer tunnel starts on the east side of the ridge and 75 feet below its top; it is 180 feet in length and extends through to the west side of the ridge. The richest ore, consisting of large masses of chalcocite with some included limestone, is encountered at a distance of 90 feet from the tunnel's mouth and continues for a distance of 21½ feet as measured in the roof. There are smaller bodies of chalcocite, however, for a distance of 10 or 15 feet on either side of the main ore body. About 115 feet from the entrance to the tunnel a winze 33 feet deep was sunk in the ore, and from the bottom a drift zigzags northward approximately 110 feet.

In 1909 a new tunnel had been driven below this longer tunnel from the southeast side of the ridge and connected by a raise with the winze. The new tunnel is 78 feet below the upper one and parallel with it. In July, 1909, it had been driven 45 feet beyond the raise but had not encountered any ore bodies as large as those of the upper tunnels. Several small lenses of chalcocite, the largest about 18 inches thick, were exposed in the tunnel itself, but the raise showed much more, for it cut the large body in which the winze was sunk. The absence of the large chalcocite bodies in the lower tunnel adds some weight to the opinion expressed after the visit of 1907 that the ore would probably not extend into the basal impure limestone beds.

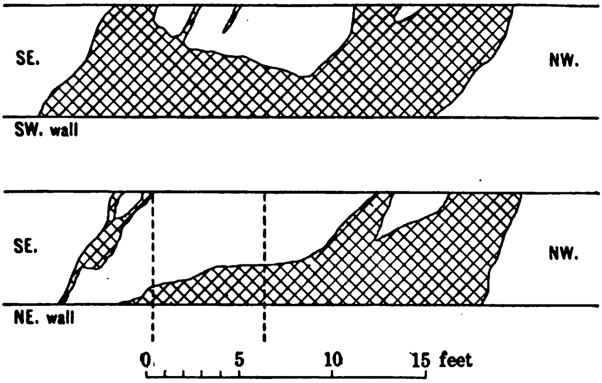


FIGURE 6.—Sketch showing form of ore body exposed in the upper northern tunnel at the Bonanza mine.

About 120 feet southwest of this tunnel is a parallel tunnel driven from the west side of the ridge and 50 feet lower than the little saddle above it on the north. This tunnel starts in a face of solid chalcocite and extends S. 33° E. for 50 feet. The ore, which is chalcocite with a small amount of azurite, is exposed for 34 feet along the tunnel, but is interrupted by horses of limestone. The remainder of the tunnel shows limestone cut by small azurite veins and in places containing a small amount of chalcocite.

A better conception of the form of the ore bodies can be obtained by an examination of figures 5, 6, and 7 than can be given in a written description. The two main parallel surface veins afford only an imperfect idea of the deposit. Those two veins represent a total replacement of limestone along minor zones, where shearing was most intense. The two tunnels show that not only is the limestone replaced along the main shear zone but that mineralized waters followed minor fracture planes also, and thus yielded the low-lying ore bodies and great irregular masses seen underground. Between and around the large masses of chalcocite the limestone was shattered and filled with many small veins of ore, which formed a stockwork that is most noticeable in the winze tunnel and on the surface northeast of the main ore body. As a rule, the brittle chalcocite is very little fractured. The limestone, on the other hand, is greatly shattered and is filled with thin veins of calcite which are older than the ore deposition. Open cavities in the fractured limestone have been filled with ice, and both the country rock and the talus on either side of this ridge, except for a few feet at the surface, are frozen all summer. The talus slopes below the ore body contain a large quantity of chalcocite resulting from weathering of the veins above and are a valuable source of copper.

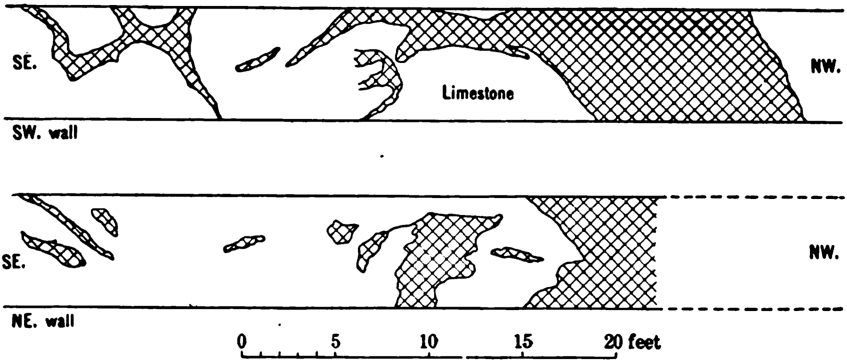


FIGURE 7.—Sketch showing form of ore body exposed in the southern tunnel at the Bonanza mine.

It is a suggestive fact that, although the main shear zone of the Bonanza mine extends from the limestone through the thin shale bed into the greenstone below, the large chalcocite bodies, so far as can be determined on the surface, end abruptly at the top of the impure shaly beds forming the lower 50 or 60 feet of the limestone. Copper minerals are associated with the shear zone in the greenstone, but only in small amount. Apparently the impure thin-bedded part of the limestone was a less favorable place for deposition than the purer massive beds above. This fact has a practical bearing on the quantity of ore present, for it is evident that if the same condition continues underground it limits the downward extension of chalcocite in the limestone. The continuation of the ore body to the northeast will probably be limited chiefly by the continuation of favorable conditions for deposition in the shear zone in that direction. The exact conditions which determined the deposition of the Bonanza ore body are not known; possibly it was the presence of a shear zone favorable to circulation; but its occurrence, together with that of the Jumbo and the Erie chalcocite bodies to the northwest, next to be described, indicates that favorable conditions for deposition have been established in more than one place and offer encouragement for seeking other chalcocite bodies at the base of the Chitistone limestone.

JUMBO CLAIM.

From the Bonanza mine the Chitistone limestone continues northwestward in a succession of lofty cliffs as far as Kennicott Glacier. The base of these cliffs is at the greenstone contact and in many places contains veinlets and stringers of azurite or chalcocite. In at least two places the quantity of these two minerals, especially of the chalcocite, is so great as to make the deposits of commercial importance.

The ore body of the Jumbo claim is 4,600 feet northwest of the Bonanza, at the head of Jumbo Creek, and is located in limestone just above the greenstone-limestone contact on a small southwestward projecting spur or angle of the limestone cliff. South of it and nearly 200 feet below is the glacier in which Jumbo Creek heads and which must be crossed to reach the ore body. The Jumbo and Bonanza ore bodies are at practically the same elevation above sea level, approximately 6,000 feet.

The limestone at the Jumbo is made up near the base of slightly cherty beds ranging in thickness from 8 to 12 inches. The strike is N. 65° W., the dip 35° N. A tunnel 12 feet long was started on the south face of the ridge, 10 feet above the greenstone. The limestone is jointed or cut by minor faults parallel to the bedding and is crossed by veins of calcite from 1 to 2 inches thick. Thin veins of chalcocite and azurite accompany them and fill some of the fractures. Seven feet above the tunnel mouth is the east end of a large chalcocite mass which is well exposed on the axis of the ridge. As indicated on the surface, this body of ore is a mass of solid chalcocite 30 feet long, 6 feet by 4 feet 6 inches at the west end, and tapering to a diameter of 1 foot at the east end. It appears to be a rudely lenticular or possibly a conical body, but has irregularly shaped protuberances, as may be seen at the west end, where the steep west face or slope of the spur gives a cross section of the ore body. (See fig. 8.)

A little way east of the Jumbo tunnel is a second tunnel in limestone a short distance above the greenstone. The tunnel runs nearly north or slightly to the northeast in limestone that strikes N. 65° W. and dips 25° N. In the tunnel, which is 12 feet long, the limestone is crushed and jointed. Small veins of calcite and azurite up to 2½ inches in thickness fill joint cracks, especially a set of perpendicular minor faults or slip planes running N. 70° W. No chalcocite is exposed in this tunnel, but it is believed that the azurite indicates its former presence. Fifty feet below the tunnel a lenticular vein of chalcocite 3 inches thick at its widest part and 3 feet long was found in the limestone.

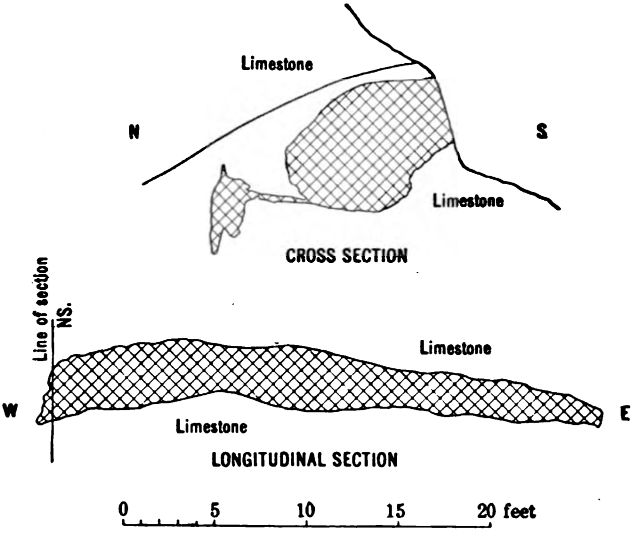


FIGURE 8.—Sketch of the ore body at the Jumbo claim.

ERIE CLAIM.

The Erie claim is the property of the Kennicott Mines Company and is situated on a steep mountain slope near the east side of Kennicott Glacier, 3¾ miles north of Kennicott, at the mouth of National Creek. The discovery point is a little more than 1,000 feet above the nearest point of the glacier and is at the limestone-greenstone contact, which here strikes N. 78° W. and dips 38° N. Between the limestone and the greenstone is a bed of greenish shale of variable thickness, but ranging from 12 to 18 inches. There is also a very thin bed of shale not more than 1 inch thick in the limestone 8 inches above the base. There appears to have been movement between the limestone and the greenstone along their plane of contact, and they were further disturbed by small faults cutting across the contact at high angles to the bedding in such a way that at one place a wedge of greenstone projects into the limestone. The larger shale bed contains many nodules of chalcopyrite from one-half inch to 2 inches in diameter, and with the chalcopyrite there is associated more or less bornite in the larger nodules. Abundant scales of azurite are scattered through the shale. No development work has been done on this claim further than to clear away the débris and make an open cut along the contact so as to expose the copper-bearing shale.

INDEPENDENCE CLAIMS.

The Independence group of claims, belonging to the Kennicott Mines Company, is on the east side of the divide that separates the head of Bonanza Creek from McCarthy Creek and is from 900 to 1,000 feet lower than the saddle where the limestone-greenstone contact crosses the ridge. The copper minerals occur in small veins that contain considerable calcite and belong to a sheeted zone striking N. 38° E., thus crossing the contact almost at right angles. This zone passes from the greenstone into the limestone and has its greatest width (about 50 feet) at the contact. The ore is found in the greenstone only and consists essentially of chalcocite, which fills fractures and is disseminated through the greenstone. It is later than the calcite filling of the sheeted zone and gradually disappears with increasing distance from the zone of mineralization. The main shear zone intersects a system of quartz-epidote veins striking N. 78° E. and carrying a small amount of bornite. There is a marked similarity between the occurrence of copper sulphides in the greenstone at this locality and at the Bonanza mine, but there is no chalcocite body in the limestone of the Independence claim.

MARVELLOUS AND BONANZA EXTENSION CLAIMS.

The shear zone in which the Bonanza ore was deposited extends in a direction about N. 30° E. from the Bonanza mine for a distance of more than a mile. It crosses the saddle between Bonanza Creek and the glacier on the north and extends to the high point of the ridge running northeast from Bonanza Peak. It was not traced beyond that point. There is no evidence of displacement, but there is a shear zone of indefinite width made up of innumerable small parallel fractures filled with calcite and crossed by minor fault planes. These fault planes are believed to have had an important and perhaps a controlling influence in the deposition of copper.

All the Bonanza fault northeast of the Bonanza property is owned by the Mother Lode Copper Mines Company and the Houghton Alaska Exploration Company. The principal exposures of copper minerals are on the Marvellous claim, where a number of short tunnels have been driven. The Marvellous claim is on the north side of the glacier east of Bonanza Peak and is about 2,800 feet above the valley of McCarthy Creek.

At the south tunnel of the Marvellous the limestone is cut by numerous closely spaced parallel joint or shear planes, many of which are filled with calcite and are conspicuous because they are lighter in color than the surrounding limestone. They strike N. 70° E. and dip 70° to 80° N. The tunnel is 15 feet under cover and exposes a vein of chalcocite from 3 to 6 inches wide striking N. 60° W. About 30 feet north of the tunnel's mouth and 25 feet lower is a vein of chalcocite in calcite that reaches a maximum thickness of 9 inches. It strikes N. 60° E. and dips 60° to 65° W. The vein is in a well-defined fault plane and can be traced for nearly 200 feet from the tunnel's mouth. In places it pinches to a thickness of 1 inch and carries no ore. Fine specimens of covellite in chalcocite were obtained from this locality. There is a second parallel vein 12 feet to the north, but it is not so long.

The main tunnel of the Marvellous is 300 feet northeast of the south tunnel and runs 100 feet S. 85° W. in dark-gray limestone. The vein is a stockwork of small calcite veins, with chalcocite and azurite in crushed limestone. About 20 feet from the face is a crosscut 9 feet long where there is a vertical fissure in the limestone striking N. 25° E. The fissure is filled with calcite and carries chalcocite and azurite. It has a thickness of 6 inches. The limestone is much discolored by iron oxide. Above the tunnel is a large mass of azurite formed by the oxidation of chalcocite whose downward extension the tunnel was expected to strike.

A third tunnel, called the north tunnel, was started on the Marvellous claim 200 feet northeast of the main tunnel and 100 feet above it. The copper minerals at this exposure occur along bedding planes of the limestone, which here strikes N. 40° W. and dips 35° E., and along fault planes that cross the bedding. The faults strike N. 10° W. and dip 44° E.

NIKOLAI CLAIM.

The Nikolai claim is located near the head of Nikolai Creek, 3¾ miles northeast of the junction of Nikolai and McCarthy creeks and 2,150 feet above it. The exposed ore body is situated near the top of the greenstone formation, about 150 feet below the base of the limestone, and is associated with a fault which cuts the limestone-greenstone contact at this place. It is composed mainly of chalcopyrite and bornite stained with oxidation products.

An examination of figure 9 will show the relation of the ore body to the associated formations. It will be seen that the limestone and greenstone beds, which here strike N. 60° W. and dip 30° NE., are cut by a fault running N. 50° E. and dipping vertically or high southeast. This fault makes an offset of 300 feet in the limestone-greenstone contact and has produced a vertical displacement of the beds amounting to 150 feet. The course that it follows in the limestone or in the greenstone at a distance from the contact is difficult to trace, but the position of Nikolai Creek east of the Nikolai mine was probably determined partly by the fault, as was also the depression between the small knob on the south side of the Nikolai ore body and the hill slope still farther south. Open spaces between the limestone and the greenstone along the fault plane were filled with masses of coarse white calcite. This filling, however, was not seen where both walls of the fault are limestone or greenstone.

The main Nikolai vein makes a slight angle with the principal fault and lies to the north of it. It strikes N. 55° E. and dips 70° SE. The ore body was produced by deposition and replacement in a shear zone in the greenstone that has a width ranging on the surface from 4 to 6 feet. Deposition of copper minerals was confined to a part of the shear zone that has a horizontal extent from northeast to southwest of 150 feet, but the shear zone itself can be traced 100 feet farther southwest and 350 feet farther northeast, making a total exposure of 600 feet.

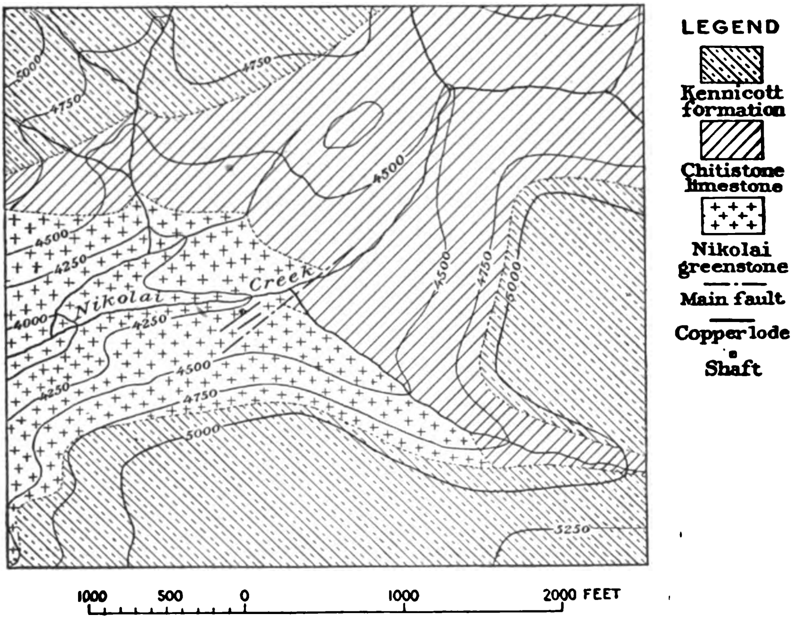


FIGURE 9.—Sketch map of area in vicinity of Nikolai mine.

Several open cuts were made on the vein and a shaft was sunk in the ore body near its northern end a few feet above the creek. Fifty feet south of the shaft two open cuts expose a second fault zone parallel to the first, along which copper minerals were deposited. It was traced for a distance of 50 feet on the surface. Moss and loose rock hide it beyond these limits, but it evidently is much more poorly developed than the fault zone to the north.

Another set of fractures or joints, with strike N. 15° W. and dip 70° W., is associated with the northeast-southwest faulting but does not appear to have resulted in any important displacement or to have offered favorable channels for circulating mineral solutions, although the openings near the main vein were followed. Still other fractures are present which were not recognized as belonging to any definite system.

The copper minerals that form the Nikolai ore body occur partly as a filling in preexisting cavities and partly as a replacement of greenstone near the cavities. The principal copper mineral is chalcopyrite, but with the chalcopyrite is associated considerable bornite. Where the copper minerals were deposited in cavities they are associated with other minerals—calcite, epidote, and quartz; where they replace greenstone the other minerals, if they can be distinguished at all, are less in evidence.

Deposition was greatest within the sheared and broken rocks of the fault zone, doubtless because the opportunity for circulation was best there. The greenstone walls, within a foot or so of the fault, are sheeted with innumerable tiny parallel fractures now filled with chalcopyrite, giving the rock a banded appearance. Deposition, however, was not confined to these veinlets. It took place also by replacement of the rock itself, so that the greenstone between the veinlets is impregnated with copper sulphide. Small veins from one-fourth to one-half an inch thick show a banding of minerals in places and give a clue to the order in which the minerals were deposited. The greenstone walls are covered by a multitude of small epidote crystals, with occasional crystals of quartz, and after them calcite was deposited. Grains and small lumps of chalcopyrite are scattered through both calcite and epidote. The ore taken from the shaft consists largely of chalcopyrite, and the dump shows that there is considerable calcite and quartz associated with it. Bornite decreases—a fact that is taken as evidence that this mineral belongs to the upper enriched part of the vein and that the ore will be found to consist of chalcopyrite as depth is gained. There has been some movement along the fault since the ore was deposited, but it probably has not produced much displacement.

WESTOVER CLAIM.

The Westover claim, which is owned by the Alaska United Exploration Company, is on the east side of Bowlder Creek, a little less than 2 miles north of the junction of Bowlder and Dan creeks. The discovery outcrop is a mass of bornite 3,500 feet above the flats of Nizina River and about 375 feet above the glacier moraine of Bowlder Creek valley. It is situated at the contact of the Chitistone limestone and the Nikolai greenstone, but the ore body is, so far as now exposed, in the limestone. Most of the limestone-greenstone contact in the upper end of Bowlder Creek valley is covered by talus from the high limestone cliffs that form the valley walls, yet in a few places, of which this locality is one, the contact is exposed for short distances. The strike of the limestone beds and the greenstone flows is here N. 15° W. and the dip is 15° E. In half a dozen or more places within the valley appear small faults cutting across the contact of the two formations and causing displacements that in several instances amount to a hundred feet or more. One or two such displacements took place a short distance south of the Westover ore body, thus bringing the greenstone at the outcrop to a higher position with reference to its nearest exposures on the south than it would have otherwise had. Both limestone and greenstone near the ore body are broken by many joints and crossed by slip planes of little displacement. Locally the rocks are much shattered and break down in small fragments. One of the most prominent of the fractures has an important relation to the ore body. It is a fault, probably of small displacement, whose contact surfaces are warped surfaces rather than planes, so that the trace of the fault on the ledge is a curved line sloping from right to left as one looks at it. This fault strikes west-northwest and dips 45° NNE. The ore body lies on the north or upper side of the fault, but is not fully exposed because the talus has been but partly cleared away from its base and the actual contact of limestone and greenstone is not in sight. Copper ore is exposed along the face of the limestone cliff at the top of the talus slope for a distance of 35 feet horizontally and at the south end of the ore body for a distance of about 10 feet vertically. The south end of the ore body is rich massive bornite and chalcocite ore, which is sharply cut off from the limestone south of it by the fault and has been formed by an almost complete replacement of limestone by the copper sulphides. On following the ore body north the richness of the ore rapidly decreases, till finally bornite disappears and only silicified limestone is seen.

The copper-bearing solutions followed all the available openings in the limestone—joints, bedding planes, and faults—and the richest ore is near such openings, for here the lime carbonate was wholly replaced by copper sulphides. The amount of replacement varies inversely as the distance from these openings till, within a few inches or a foot, the grains and tiny veinlets of bornite can no longer be seen in the limestone. Where the limestone was greatly shattered the opportunity for replacement was greater; but in the more massive parts of the beds it took place sparingly, if at all.

The sharply defined contact of ore and limestone at the fault on the south suggests that the displacement is later than the ore deposition. If this is the case, the present exposure does not show a complete section of the original ore body and further prospecting may reveal the displaced part.

OTHER PROSPECTS.

There has probably been more prospecting for copper in the Nizina district than in any other part of Chitina Valley except the vicinity of Kotsina River. Prospecting was stimulated by the discovery of such deposits as the Bonanza, the Jumbo, the Nikolai, and other claims and by the presence of a greater number of prospectors. The limestone-greenstone contact has been examined with care wherever it is accessible, and most of it has been staked. Most of the copper found is of the class of disseminated sulphides in greenstone. Examples of this class are found in the Donohoe prospects in the greenstone on the east side of McCarthy Creek and the prospects of the Alaska United Copper Exploration Company on the west side of Bowlder Creek, opposite the Westover claim, and on the east side of Bowlder Creek north of Dan Creek. The copper sulphides of the last-named locality occur along joint or fault planes, some of which are nearly parallel with the major strike fault of the Dan Creek valley and some cross these at large angles. In 1909 a tunnel was being driven on the property about one-fourth of a mile east of Bowlder Creek and 275 feet below the limestone-greenstone contact to cut a fissure carrying copper minerals that was exposed 175 feet higher to the north. A belt of greenstone with disseminated copper sulphides is found at about this distance below the limestone and extends east along the north side of Dan Creek valley. It carries small amounts of bornite and chalcopyrite, and in places a little native copper is present. The native copper is believed to be a secondary alteration product derived from the sulphide. Bowlders of greenstone carrying native copper are not unusual in the gravels of Dan Creek. Not much work has been done on the native copper-bearing greenstone, and the quantity of copper there is not yet determined. The principal prospects of this kind are on the upper part of Dan Creek and are the property of the Dan Creek Gold and Copper Company.

A small deposit of copper carbonates, malachite, and azurite is found in the limestone only a few feet above the limestone-greenstone contact south of Chitistone River, a mile east of the Nizina River valley. The copper minerals were deposited in a crushed and faulted part of the limestone and the whole is much stained with iron oxide. Two short prospecting tunnels were driven in the limestone by the Houghton Alaska Exploration Company, to whom the prospects belongs.

GOLD.

PRODUCTION.

All the gold produced in the Chitina Valley has come from the placers of Dan, Chititu, and Young creeks. Chititu Creek is the principal producer, and after it comes Dan Creek. Young Creek has had only a small output up to the present time and may almost be disregarded as a contributor in past years, but with lower freight rates and cheapened cost of production it may become of greater importance in the future. The total gold production of Chititu and Dan creeks from 1903 to 1909, inclusive, may be estimated with a considerable degree of accuracy as between $450,000 and $500,000, or an average of about $65,000 a year. There is good reason to believe that with the installation of new equipment on the completion of the railroad this yearly average will be much increased.

SOURCE OF THE GOLD.

It may be said with certainty that the source of the placer gold of Dan, Chititu, and Young creeks is in the black shales of the Kennicott formation. This is clearly shown by the distribution of the gold itself. All the tributaries that flow into Dan and Copper creeks from the northeast, including Dan Creek above the mouth of Copper Creek, lie within the limestone-greenstone area and carry no gold. All the tributaries that flow into Dan and Copper creeks from the southwest head in the shale area and all carry gold. All the gravel deposits of Dan and Copper creeks except a part of the bench and stream gravels on lower Dan Creek are derived from sources within the drainage basin of these streams. No foreign material was found, and there is almost no possibility that any could be present, for the whole basin is surrounded by steep walls which probably never were below the surface of the ice fields during the time of greatest glaciation.

All the tributaries of Chititu Creek originate within the black shale area and all carry gold, but here, as on Young Creek, part of the gravels are of foreign origin brought in by glacial transportation. Rex Creek is the one exception to this statement, for its gravels, save in the lower mile of its course, are all derived from within its own drainage basin. The gravels of the upper Rex Creek valley are derived from the black-shale area and carry gold. No evidence was obtained to indicate any other source for the gold of Chititu and Dan creeks than the shales lying between Dan and Young creeks, although all the copper and probably all or nearly all the silver of Chititu Creek came from an outside source.

Many small quartz veins carrying pyrite and native gold have been found in the black Kennicott shales between Copper and Rex creeks.

They range in thickness from less than an inch to several inches and are believed to have a close relation to the porphyritic intrusions in the shales. Molybdenite is present and stibnite is also reported from these veins. The placer gravels contain, besides the metals gold, silver, and copper, such heavy minerals as galena, cinnabar, barite, pyrite, and possibly marcasite. Native lead with a white coating, thought to be cerusite, was found in the sluice boxes on Chititu Creek, but may have been introduced by white men or natives, for bullets and shot are common. Not all of these minerals have been found in place in the rock, but it is probable that they also are associated with the quartz veins and porphyry intrusions. Thin veins no thicker than a sheet of paper are common in joint planes of the hard argillite bowlders in the stream gravels. They contain quartz, pyrite, and in places free gold. A thin vein less than one-fourth of an inch thick was found in a porphyry dike on the upper part of Rex Creek, which consisted of quartz with molybdenite and pyrite and assayed 0.18 ounce gold and 12.80 ounces silver to the ton. The dike rock near the vein, although seemingly little altered, contained pyrite and showed a trace of both gold and silver. There is thus good evidence for the source of the gold aside from that furnished by its distribution in the gravels.

The gold in the stream gravels is in part a concentration from the bench gravels through which the streams have cut their channels and in part a concentration from the products of weathering derived directly from the shales and the auriferous veins. Probably the greater part is a reconcentration from the older deposits. Extensive accumulations of high bench gravels are present on both Dan and Chititu creeks. They are best developed on the lower parts of the streams but extend into some of the tributary valleys. The bench gravels of Dan Creek extend west from the neighborhood of Copper Creek and around to the west slope of Williams Peak,[a] where they reach an elevation of over 1,200 feet above the flats of Nizina River. The bench gravels of Chititu Creek reach an elevation as great as or greater than those of Dan Creek. In both places they represent a filling in old valleys through which the present streams have cut their channels and in so doing have reconcentrated a great volume of older deposits, derived partly from the upper Nizina Valley and the region east of the heads of White and Young creeks but chiefly from the drainage basin of Dan and Chititu creeks. When the bench gravels were laid down the two great ice streams that came down the Nizina and Chitina valleys were still in existence, although on the retreat. They formed the barrier behind which it was possible for such deposits to accumulate and brought to the bench gravels that part of them which is foreign to Dan and Chititu creeks. It is impossible to say what proportion of the gravels consists of foreign material, but it is believed to be the smaller part. Some of the bench gravels carry gold in sufficient quantity to be of commercial importance, as has been proved at a number of places. A reconcentration of such deposits accounts in part for the greater richness of the stream gravels. The process that brought about this concentration is exactly the same in principle as that carried on in the miners' sluice boxes on a much smaller scale but in a much shorter time. This concentration is probably slower at present than it was before the streams had cut through the deep gravel accumulations and intrenched themselves in the underlying hard rock, but it still goes on, for erosion of the bench gravels has not ended.

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[a] Williams Peak is named in honor of John M. Williams, a pioneer prospector of the Nizina district, who was killed in a snowslide on Bonanza Creek on April 7, 1909.

PLACER DEPOSITS.

DAN CREEK.

Dan and Copper creeks may well be regarded as one stream in spite of whatever accident or design resulted in their having different names and of the fact that the upper part of Dan Creek sometimes carries as much or more water than Copper Creek. A reference to the geologic map (Pl. III, in pocket) will show that the two streams follow closely, the course of the fault that gave the older greenstone and the limestone on the north their relative elevation above the base of the Kennicott formation. With unimportant exceptions, the north side of the Dan and Copper creek valleys is in limestone and greenstone, the south side in shales of the Kennicott formation. Most of Copper Creek is in a broad glaciated valley, but at a point nearly 1 mile above its mouth the creek enters a narrow rock-walled canyon that opens slightly below Copper Creek yet extends down Dan Creek nearly a mile. Dan Creek valley below the canyon is narrow and shut in by steep mountains as far as the flats of Nizina River.

During the ice invasion the Copper Creek valley was swept clear of whatever unconsolidated deposits may have accumulated, and the form of the valley was considerably modified. When the ice was retreating some glacial débris was left on the valley floor, but it is of less importance in connection with the gold placers than the accumulations of stream gravels that have been laid down since the glacier disappeared. In this respect the placers of Copper Creek are different from those of Dan Creek.

All the tributaries of Copper Creek on its south side, as Idaho, Rader, and Seattle gulches, carry gold, but most of the output of the creek comes from near the mouth of Rader Gulch. Part of the gold is from the gulch itself and part is from Copper Creek, just below the gulch. The gravels are all shallow. Those in the mouths of the gulches are composed almost entirely of shale, chiefly from the Kennicott formation but also in part from the McCarthy shale. They occupy narrow gulches and accumulate so rapidly that the streams have difficulty in removing them. The gravel deposits of Rader Gulch are of this character. They consist of loose shale fragments and occupy only a few hundred feet of the lower end of the gulch, for above them the grade is so high and the channel so narrow that the water removes loose material rapidly. The gravels of the main stream contain material from all the formations within the drainage basin. At Rader Gulch they form a narrow flood-plain area between the mountain slope on the southwest and a low ridge on the northeast. They contain considerable coarse material mingled with blocks and bowlders of glacial origin and much fine material derived from the shales. The gold is not a concentration from older, lower-grade deposits but is derived directly by weathering and by stream concentration of the products of weathering. The source of most of the gold is clearly indicated by its position in the gravels at and just below the mouth of Rader Gulch and the presence of workable gravels on the lower part of Rader Gulch.

Idaho and Seattle gulches resemble Rader Gulch in their form and the character of their gravel deposits, but they have not been found to carry as much gold.

Copper Creek is difficult to reach with supplies except in winter, for the canyon makes necessary a high climb of more than 1,000 feet around the side of Williams Peak. Men on foot, however, can follow the creek. Logs have been placed across the stream in the canyon and make it possible to avoid bad places. Mining on Copper Creek is done with pick and shovel. There is a small supply of timber for firewood and for sluice boxes, but it would not be adequate for extensive mining operations. Good timber for lumber can be secured along Nizina River, but the expense of carrying it to Copper Creek under present conditions, except in winter, would be great.

The gold of Dan Creek has a less simple history than that of Copper Creek. It is in part a reconcentration from older gold-bearing bench gravels and in part, like that of Copper Creek, a concentration from the products of later erosion. Old high-bench gravels are found on both sides of Dan Creek, especially on the lower part, but near the west end of the canyon they lose their prominence and disappear altogether at or below the mouth of Copper Creek. Dan Creek has cut its present channel down through this great accumulation of glacial and stream deposits and into the shales beneath. The stream gravels consist of greenstone, limestone, and shale. They form between rock walls a narrow flood plain overgrown with timber and in many places of less width than a placer claim. A large part of the gravels consists of bowlders ranging from cobbles to masses several feet in diameter. Most of them, however, are not too large to be moved by hand. All the fragments are rounded. They were deposited by a rapidly flowing current and the bedding is poor. Buried spruce logs and fragments of wood are common. The gravel and its slight covering of soil range from 8 to 12 feet in depth.

Dan Creek gold is coarse and smooth and is accompanied by silver and copper. It has been concentrated on bed rock or within the lower 2 feet of the gravel. A large proportion, however, finds its way into the cracks and crevices in the shale, so that in places a foot or more of the shale has to be removed to recover all the metal. An unusual feature of the gravels of Dan Creek is the small quantity of fine gold found in them. Very little fine gold is recovered in the sluice boxes and practically none is found in panning. Numerous prospect holes show that the gold is well distributed across the channel and have failed to discover the presence of a concentration into a defined pay streak. Beside the holes sunk on the flood plain, tunnels have been driven along bed rock at the base of the bench gravels above the present flood plain. The depth to which the creek has incised itself in the shales is not constant but is rarely less than 10 or 15 feet. Thus the base of the bench gravels or the "rim" of the channel stands well above the creek. The tunnels driven in the bench gravels show the presence of gold in sufficient amount to be of commercial importance and in several places in sufficient amount to pay for extraction under the expensive methods necessary in prospecting the gravels, but the final test of value will come when an attempt is made to extract the gold on a large scale.

An old channel formerly occupied by Dan Creek lies in the bench gravels on the south side of the present stream. It runs on the south side of the small round hill west of the mouth of Copper Creek and follows the hillside to the west, but it has not been traced definitely. Doubtless much of it has been removed by erosion. Its gravels carry gold, and an attempt has been made to exploit them in a small way. but without great success.

Dan Creek is favorably situated with reference to timber for mining purposes and has a good supply of water. It is reached without any difficulty from the Nizina, and a wagon road for hauling timber and supplies has already been built. All mining to the present time has been by the simplest methods. The one employed for several years is to undercut the bank with a stream of water and by washing away the gravel to leave the gold. Bowlders and small rocks are piled parallel with the bank and only a few feet from it. Then water controlled by dam and gates is turned in and forced against the bank, undercutting it and carrying away most of the fine gravel. The large rocks are piled back by hand and the remaining fine gravel and gold are shoveled into sluice boxes, after which bed rock is cleaned. Preparation has been made for installing a hydraulic plant on Dan Creek, and it will be put in place as soon as the railroad is completed and better facilities for carrying freight are established.

CHITITU CREEK.

Chititu Creek and its two branches, Rex and White creeks, lie wholly within the area of Kennicott sediments. These streams, like Dan Creek, have cut their present channels through the old valley filling and entrenched themselves in the black shales. The amount of this entrenchment is variable, ranging from nothing below the canyon on Chititu Creek to 60 or 70 feet on White Creek, but the increase is not uniform. It is about 30 feet at the mouth of White Creek, but is greater than that in places farther down on Chititu Creek. It decreases as Rex Creek is ascended and also on the head of White Creek. The canyon on Chititu Creek is due to the presence of a large porphyry dike in the black shales, which has protected them from rapid stream cutting and confined the water to a narrow channel. The canyon is small but marks the downstream limit of gold-bearing gravels that are now considered of commercial importance.

Above the rim of the shallow trench cut in the shales by the stream are steep banks of rudely assorted gravels. The top of the gravel bluff at Sunday Gulch is a little more than 500 feet above Chititu Creek. Half a mile downstream the top of the bluff is 750 feet above the creek, but from this point on the difference grows smaller till the bench gravels merge into the gravels of Nizina Valley a short distance below the canyon. Bench gravels are prominent on Rex Creek for a mile or more above its mouth, but they either were not deposited or have been removed from the upper end of the creek, where the unconsolidated accumulations are wholly glacial débris. A large part of the bench deposits of White Creek have been eroded away, yet they extend up the creek in conspicuous exposures for at least 2 miles.

The richest gold-producing gravels of Chititu Creek are the stream gravels; they include all of Chititu Creek above the canyon, together with a large part of Rex and White creeks. The most important parts of these creeks, viewed from the standpoint of gold production, are represented on the sketch map (fig. 10). The stream gravels cover the floor of the shallow rock-rimmed trench to a depth of 8 to 16 feet, depending partly on the form of the bed-rock surface and partly on the irregularities of deposition by a swiftly flowing current. They form a flat, originally covered with timber and underbrush, ranging in width from 200 to 700 feet. The gravels of Chititu and White creeks and of the lower part of Red Creek consist of shale, limestone, sandstone, and quartz diorite porphyry, all of local origin, mingled with greenstone, diorite, and other rocks brought in by glacial ice from a foreign source. Shale, sandstone, and porphyry make up the fragmental deposits of the upper part of Rex Creek.

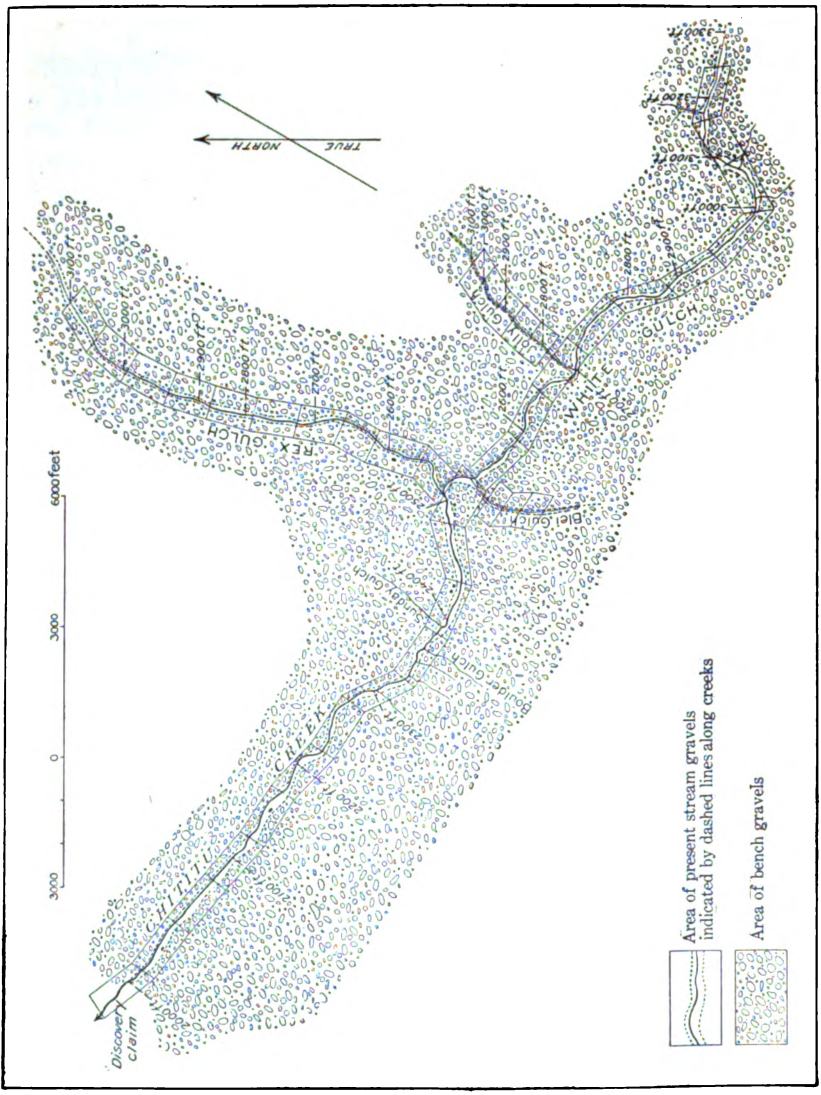

FIGURE 10.—Sketch map of a part of Chititu, Rex, and White creeks, showing the location of claims and the relation of bench and stream gravels.

Bowlders and large blocks make up a considerable portion of the gravel deposits, but not so large a proportion as on Dan Creek. Some of the glacial erratics are 6 or 8 feet in diameter. Most of the bowlders, however, can be sent through the sluice boxes, although it is necessary to break part of them with powder.

The gravels producing gold at present include those of Chititu Creek and of the lower part of Rex Creek. Very little work aside from that necessary to hold the claims has been done on White Creek for several years. In a general way the gold of Chititu Creek is distributed through the gravel from rim to rim of the rock channel, but it was found that at one place near the canyon there is a very well-defined pay streak, such as had not been found before on any of the claims farther up the creek. Most of the gold is on or near bed rock. Very little of it is found in the upper part of the gravel. The gold penetrates the bed rock through cracks and all openings, so that it is necessary to clean the rock carefully by hand after taking up the loose upper part to the depth of a foot or more. There are considerable differences in the character of the bed-rock surface, owing to irregularities in form and differences of hardness. In places the old stream has worn the rock smooth or has hollowed out cavities and depressions. Differences in the depth of weathering also add to the irregularities of the exposed surface, for the streams of water from the hydraulic giants cut away the loose rock and leave the harder parts standing in relief. Without doubt much of the gold of Chititu, Rex, and White creeks is a concentrated product from the bench gravels and the remainder is derived directly by weathering from the surrounding shales. All the bench gravels carry gold in some amount, and with decreased cost of mining it is probable that some of them will be exploited.

Chititu gold is finer and less worn than that of Dan Creek. It was found on the lower part of Chititu Creek that in a set of 4 screens ranging from 10 to 20 mesh about equal amounts of gold, by weight, were caught in each screen; at the mouth of Rex Creek it was estimated that from 25 to 40 per cent of the gold passes through a 16-mesh sieve. These results are in marked contrast with the heavy coarse gold of Dan Creek, yet both come from the same area of mineralization. There is, nevertheless, a little coarse gold on Chititu Creek, and several large nuggets have been found. The gold assays about $18.70 per ounce when cleaned. A large quantity of copper is obtained in the clean-up, and nuggets of native silver are common. Several other heavy minerals besides copper and silver are caught in the sluice boxes, such as pyrite, galena, stibnite, barite, and lead. Most of the lead was evidently introduced through the use of firearms, but some of the pieces examined did not resemble the battered bullets found in the sluice boxes and had a thick white coating of oxidized material. One of the largest of the native-silver nuggets was found in 1909; it weighed over 7 pounds but contained considerable quartz.

Native copper is a source of considerable difficulty and expense in mining. Several hundred pounds of fine copper are secured at every clean up and many large masses are taken from the cuts. Occasionally a large piece goes through the boxes and into the dump, but the largest are too heavy to be driven out of the cut by the giant. All the gold is picked over by hand to remove the fine copper not separated in the sluice box. During the early days of mining no effort was made to save the copper, since the expense of carrying it to the coast was greater than its value, yet with railroad transportation it should now be worth considering.

For the first few years after the discovery of gold on Chititu Creek mining was conducted on Rex and White creeks as well as on Chititu Creek. Rich ground was found on all these streams, and the principal operations were on the upper half of Chititu Creek, the lower end of Rex Creek, and the upper part of White Creek. All the work was done by hand and attention was directed to the richest ground only. At present two hydraulic plants are in operation, one on Chititu Creek and the other at the mouth of Rex Creek. Most of the claims on Chititu Creek are owned by the Nizina Mines Company and a complete hydraulic plant has been installed to exploit them. This plant includes flumes, pipe lines, and giants, as well as a complete sawmill and an electric lighting system. The sawmill is equipped with planers and machinery for turning out standardized parts of flume and sluice boxes and riffle blocks and for putting them together. There is also a blacksmith shop and equipment for handling iron pipe. A very unusual feature for an Alaska placer mine is the complete system of accounting by which all expenses are charged in their proper place and the cost of any part of the operations is made known.

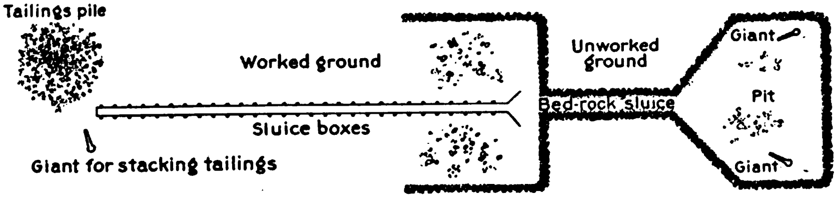

FIGURE 11.—Diagram showing the method of operating hydraulic giants on Chititu Creek.

The method of handling gravel in the pit is shown in figure 11. When the sluice boxes have been put in place a bed-rock flume is carried upstream in the gravels as far as desired. Then the upper end of this cut is widened to 100 or 150 feet and a giant is placed on either side so as to drive the gravel along the sloping face into the head of the flume. By this method the force of the giants is added to the ground sluice water and a decided gain in efficiency is obtained over the former method of working against the face with the giants turned upstream and away from the sluice boxes. In practice only one giant is used at a time, the opportunity thus being given for a gang of men to remove the large bowlders on the opposite side. A giant is also required at the lower end of the sluice boxes to stack the tailings and keep the end of the boxes clear.

Mining operations at the mouth of Rex Creek have been conducted by Frank Kernan with a smaller plant than that on Chititu Creek, but they have been carried on for a longer time. A small giant is used and water is brought from Rex Creek in a flume. The conditions here are about the same as on Chititu Creek, but the width of gravel between the rock rims is less. Some very rich ground has been found on the lower end of Rex Creek and just below that on Chititu Creek.

The canyon of Chititu Creek is 4½ miles from the flats of Nizina River, and the character of the country is such that a good wagon road could be constructed at moderate expense. Such a road in connection with a bridge over the Nizina River would make communication with the railroad at Kennicott River easy and would be of great advantage to the miners of Chititu Creek, since it would enable them to secure supplies at any time of the year at a reasonable cost. It would also do much to solve the problem of securing labor at the time when it is most needed and thus prevent the necessity of carrying a large force of men on the pay roll during the whole season. Labor is a large item in the expense of operation at present chiefly because of the large amount of time spent in winter freighting. Wages range from $90 per month and board to $5 per day, with an additional amount to foremen.

Chititu Creek has a sufficient volume of water for all the demands that are made on it by the hydraulic plant in operation. The supply on Rex and White creeks is naturally less and probably would be inadequate for a large plant at some seasons of the year. Chititu Creek has a fall of 180 feet per mile from the forks to the canyon. Rex and White creeks have a fall of 250 feet per mile in the lower 2 miles of their courses. Thus a good head of water can be secured on each of these streams. There is an abundance of good timber for lumber and mining purposes on Chititu Creek below the canyon.

YOUNG CREEK.

Young Creek resembles Dan and Chititu creeks in having cut its channel through an old gravel filling in a glaciated valley. The present stream flows in a trench cut in black shales and lies from 20 to 40 feet below the base of the bench gravels. Its channel is in reality a shallow canyon whose walls are shale at the base and gravel above. Young Creek valley was once occupied by a glacier which came into it across a broad low divide near its head and was an overflow branch of the great Nizina Glacier. The gravels of Young Creek therefore contain a large amount of foreign material from the upper Chitina Valley in addition to rocks of the Kennicott formation and the greenstone from its own valley.

A large part of the creek has been staked for placer gold, although the production has not yet been enough to give much encouragement for mining. Two men were prospecting on the lower part of the stream in 1909. In previous years work was done on Calamity Gulch also, but the results were not sufficiently favorable to lead to its continuation.

Young Creek carries a large stream of water at all seasons of the year and has an average fall of 100 feet per mile above the Nizina flats. It is difficult to reach the upper part of the creek because of the canyon-like character of the stream channel and of the absence of trails above the creek on the hill slopes, and for this reason it is customary to cross the ridge from the head of White Creek and come down on Young Creek at the head of Calamity Gulch. This is the route always followed by prospectors bound for the head of Young Creek.

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 449

A GEOLOGIC RECONNAISSANCE IN SOUTHEASTERN SEWARD PENINSULA AND THE NORTON BAY-NULATO REGION ALASKA

BY

PHILIP S. SMITH AND H. M. EAKIN

WASHINGTON
GOVERNMENT PRINTING OFFICE
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PREFACE.

By Alfred H. Brooks.

For several years after the organization of the Alaskan surveys in 1898 most of the appropriation was devoted to exploration. These exploratory surveys, although they had no high degree of accuracy, served to block out the larger features of the topography and geology, and the resulting reports and maps proved of great value to the pioneer prospector and miner. With the advance of the mining industry came a constantly increasing demand for maps which were based on a higher degree of refinement both with reference to geologic observation and to mensuration. To meet this demand areal surveys were begun first on a scale of 4 miles to the inch and later, where the mining interests warranted it, on a scale of 1 mile to the inch. The rapid industrial advancement in many parts of Alaska led to the expansion of surveys of this character almost to the exclusion of the purely exploratory work.

The progress made in reconnaissance and detailed surveys has seemed to warrant again diverting a part of the funds to exploring some of the little known regions. One of the largest of the unsurveyed areas in the more accessible parts of Alaska is roughly blocked out by lower Yukon and lower Koyukuk Rivers on the east and Norton Bay and Seward Peninsula on the west. This field was selected for survey because it was thought that the metamorphic rocks of the Seward Peninsula might occur within it, which would give presumption of the presence of auriferous deposits. The results of the investigation of this area are presented in this report.

In addition to exploring the region east of Norton Bay the party also extended the topographic and geologic mapping into the southeastern part of the Seward Peninsula, thus extending the surveys of Peters and Mendenhall, made in 1900. In this part of the field the results were sufficiently definite to warrant their publication in a map on a scale of 4 miles to the inch. The remainder of the survey, based as it was on foot traverses, which afforded little opportunity for areal mapping, seemed hardly sufficiently accurate to warrant the publication of maps on a larger scale than 16 miles to the inch.

Messrs. Smith and Eakin deserve great credit for the large amount of information gleaned during their very hasty exploration. The results form a notable contribution to the geology and geography of a region that was previously almost unknown. Though the economic results so far as most of the region is concerned are largely negative, they are, nevertheless, of no inconsiderable value. The geologic maps will indicate large areas which do not seem worthy of attention on the part of the prospector.

Besides covering the Norton Bay and lower Yukon region in an exploratory way, the report and its maps furnish the details about the southeastern part of the Seward Peninsula necessary to complete the reconnaissance work in that province. The publication of this report marks the close of the reconnaissance work in the Seward Peninsula which was begun a decade ago.

A GEOLOGIC RECONNAISSANCE IN SOUTHEASTERN SEWARD PENINSULA AND THE NORTON BAY-NULATO REGION, ALASKA.

By Philip S. Smith and H. M. Eakin.

INTRODUCTION.

West of Koyukuk and Yukon rivers a large area has long remained geologically unexplored. In a portion of this region an exploration party from the United States Geological Survey worked during the season of 1909, and the results of the studies there carried on and extended as far as Council, in Seward Peninsula, are set forth in this report. The party consisted of the writers, A. G. Winegarden, packer, and a cook. Supplies for a month were shipped to Nulato, the point from which the expedition set out, and the camp equipment and supplies were transported in the field by a pack train of four horses. Other supplies, sufficient to last the rest of the season, were sent to Nome and then transported, through the courtesy of the Wild Goose Company, to the mouth of the Koyuk and there cached to await the arrival of the party.

After many delays the party arrived in Nulato on the afternoon of June 24 and immediately began to get the outfit into condition for the trail. On the morning of June 26 active field work was begun. The route, as indicated by the location of the camps on the maps (Pls. I and V, in pocket), was westward to Ungalik River, thence northward to the Koyuk, which was reached on July 16. Here a halt was made until supplies from the cache could be obtained and the outfit put into shape for the next trip. On July 19 the party started northeastward along the divide between the Inglutalik and the Koyukuk drainage basins. This survey was carried eastward to the divide between Kateel and Inglutalik rivers. Return to the Koyuk was made along the divide between the drainage basins of the Buckland and the East Fork of the Koyuk, and a tie was made on the previous geological work of Moffit in northeastern Seward Peninsula. At the close of the trip the Koyuk was crossed near the mouth of East Fork, and the party arrived at the Koyuk cache on August 8. A severe storm and the work of replenishing supplies and making necessary repairs delayed setting out again until August 12, when the party got under way and made a meandering traverse of the areas between Koyuk River and Norton Sound that had not been visited by Mendenhall in his expedition of 1900. Moving along the divide between the Koyuk and the Norton Sound drainage basins, the party swung around the head of the Tubutulik, thence crossed the divide into the Fish River drainage basin, and, following along the foothills, came to the Omilak mine. From the mine the course was southeastward to the Kwiniuk and thence along the coast to Walla Walla. Supplies had been sent to this point from the mouth of the Koyuk, so that the horses had been able to travel light. From Walla Walla meandering traverses were made westward to Cheenik, which was reached September 17. By this time the top of the ridges were snow covered, and a start was made the next day for Council by way of the Kachauik-Fish River divide. Council was reached and the fieldwork for the season was stopped on September 21.

Locations were kept by continuous foot traverses run by each of the geologists independently and elevations were frequently noted by aneroid barometers. The barometric observations, however, were unchecked and served principally to give relative elevations. The foot traverses were paced, directions being obtained by means of Brunton compasses. The results of the different traverses were platted in the office by making adjustments between known points which had been determined instrumentally either by the Coast and Geodetic Survey or by Peters on the reconnaissance trip of Mendenhall in 1900. So closely did the various traverses check on known points that it is believed that, after the adjustments were made and the map prepared, few, if any, points were more than a mile out of their correct positions. That this apparently rough method of pacing is capable of giving good results is shown by the fact that the difference between the position of Camp A15, near the Bonanza mine, on the Ungalik, as determined by the two geologists, after having made a linear traverse of over 130 miles, was less than 5 miles. This result was obtained on the erroneous premise that both were pacing 2,000 paces to the mile. When, however, an individual rating had been obtained by comparing the scaled and paced distance to the mouth of the Koyuk and this correction had been applied to the location of Camp A15, it was found that the difference between the two traverses was considerably less than 1 mile.

Hearty acknowledgments are due to Mr. A. G. Winegarden, of Gardiner, Mont., who acted as packer throughout the various trips, for his unceasing activity in furthering the aims of the expedition and his willingness to perform more than his share of the camp work in the face of rather discouraging conditions. Thanks are also expressed for the friendly assistance of Mr. C. H. Munro, of the Wild

Goose Company, and to Messrs. Thomas Moon and John Lindburg, prospectors, in distributing supplies at appointed places and thus facilitating the movements of the party.

The writers desire also to express their appreciation of the work of the earlier geologists and engineers who have visited portions of the region or contiguous areas, and from whose published reports and manuscripts they have borrowed to supplement their own observations. Among those to whom the writers are most indebted for scientific information are Messrs. J. L. McPherson, W. C. Mendenhall, F. C. Schrader, F. H. Moffit, and A. H. Brooks; for the determination of the fossils collected they are indebted to the paleontologists of the United States Geological Survey.

GEOGRAPHY.

LOCATION OF AREA.

The area in which new geographic and geologic information has been obtained may be inferred from the description of the itinerary of the expedition of 1909. It has seemed feasible, however, to so extend the area actually visited as to include contiguous regions which throw light upon parts of the region visited in 1909 or in which the results of 1909 serve to confirm or explain problems raised by other investigators. The area treated in this report is therefore in the main rectangular and may be roughly described as bounded by parellels 64° and 66° north latitude and by meridians 156° and 164° west longitude. Described in terms of places and natural objects, the southern margin is near the settlement of Unalaklik, on the east coast of Norton Sound, and the eastern end of the northern margin is a short distance north of the big bend of Koyukuk and Kateel rivers and the western end is a short distance north of the town of Candle on Kiwalik River in the northeastern corner of Seward Peninsula. On the east the region is bounded by a north and south line passing a little east of the junction of the Melozitna and Yukon rivers; on the west the best known point to which to refer the margin is the town of Council on Niukluk River. The area can be best comprehended by reference to the general map of northwestern Alaska (fig. 1), and to the more detailed maps, Plates I and V. For several reasons it has been decided to show the eastern part of this region separately from the western. This has been done mainly because better information has permitted mapping of the western portion on a scale of approximately 4 miles to the inch, whereas the eastern portion is shown on Plate V on a scale of approximately 16 miles to the inch. A division of this sort separates the great sandstone shale area of the east from the more highly metamorphic areas of the west. In this report the eastern area, the one represented by

Plate V, will be referred to as the Nulato-Norton Bay region, and the western part (Pls. I, VI) will be called southeastern Seward Peninsula.

HISTORY OF EXPLORATION.

Prospectors and trappers have without doubt wandered over the region described in this report, but there is little or no record of their journeys and the facts that they learned have been lost. Other classes of travelers seldom ventured far from the main avenues of intercommunication; consequently, until within the last 10 or 15 years there have been few published references to any part of the region except the coast line, the Yukon and Koyukuk rivers, and the Kaltag portage. It is not intended at this place to give an account of all the exploring expeditions that have visited the waters surrounding Seward Peninsula, Norton Sound, and Bering Sea, and the reader who desires a more complete historical sketch is referred to the papers of Brooks[a] and Dall.[b]

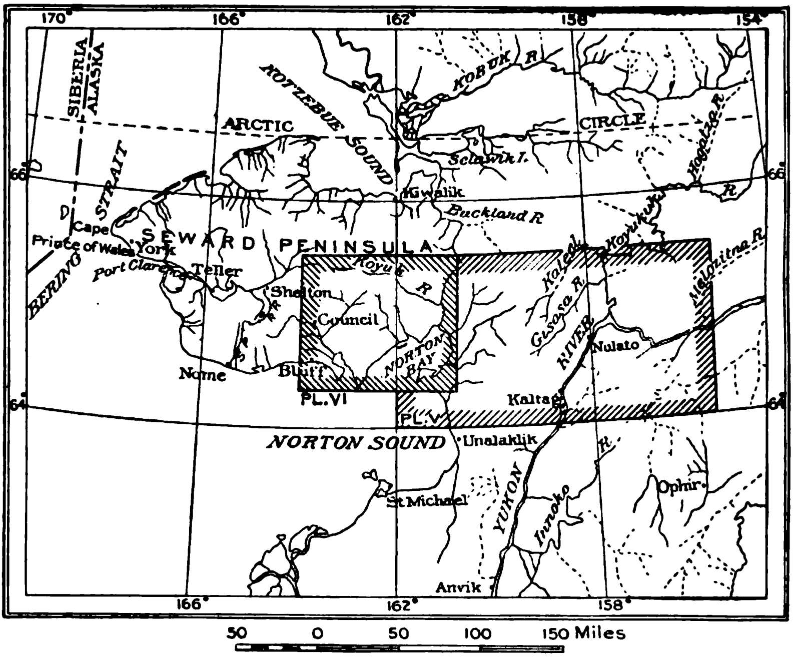

FIGURE 1.—Sketch map of northwestern Alaska, showing location of region considered.

The oldest settlement in this part of Alaska was at St. Michael, where, according to Dall,[c] Michael Tebenkoff, an officer in the Russian-American Trading Company, established a post in 1833. From this point trading was carried on with the surrounding country. Soon other posts were established. Thus in 1838,[a] Malakoff, a creole, explored the Yukon as far north as the present town of Nulato and established a small settlement at the mouth of Nulato River. He left this post undefended during the winter of 1838–39 and it was destroyed by Indians. Soon afterward, in 1840, a trading post and fort were established on Norton Bay near the mouth of Unalaklik River and called by the name of the stream. This town, according to the 1900 census, had a population of 241.

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[a] Brooks, A. H., Geography and geology of Alaska: Prof. Paper U. S. Geol. Survey No. 45, 1906.

[b] Dall, W. H., Alaska and its resources, Boston, 1870, 627 pp. and map.

[c] Idem, p. 9.

In spite of the destruction of the first settlement at the mouth of Nulato River the Russian-American Trading Company, appreciating the importance of this place as a point giving ready access to the Koyukuk basin, sent Dérabin in 1841 to rebuild the fort. This was done, and in 1842 Lieutenant Zagoskin of the Russian navy visited the place. His visit is of interest because he made several short journeys into adjacent areas and published the results of his observations.[b] Although his accounts are fragmentary and imperfect, they show that he visited portions of Yukon River as far upstream as the mouth of the Melozitna, explored Koyukuk River as far as the mouth of the Kateel, and made a side trip up the Kateel to assure himself that the native reports of an easy route into the Buckland drainage basin were correct. Unfortunately the maps published with his report are not based so much upon his direct personal observations as upon reports heard by him, and consequently many of the features are indicated only in a most general manner.

In 1851 the trading post and fort at Nulato were burned and some of the inhabitants were massacred by Indians from the Koyukuk. When the town was rebuilt it was moved a mile or more up the river to its present location on a low gravel bench between Nulato Slough and Nulato River.

About 1850 the great activity among many of the different nations, notably the English, in searching for the Franklin expedition resulted in several ships wintering in the waters of Kotzebue Sound. From these ships several exploring parties visited neighboring areas and added geographical data. Of these expeditions few prepared maps of sufficiently large scale to portray any but the most general features of the region explored. Among the overland trips were the exploration of Selawik Lake and vicinity by Surgeon Simpson of H. M. S. *Plover*, the trip from Chamisso Island by way of Buckland and Koyuk rivers to St. Michael by Lieutenant Pim of the same ship, and the exploration of Buckland River by Captain Kellett and officers of H. M. S. *Herald*. Accounts of the voyages of the *Herald*[a] show that the last-named expedition went up the Buckland for 30 miles (probably measured along the circuitous course of the river) in a whaleboat and then about 30 miles farther in lighter boats. The Pim journey is also described in the same publication, but the narrative is more a recital of hardships than of geographic or geologic data and is not accompanied by a map.[b]

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[a] Dall, W. H., Alaska and its resources, 1870, p. 48.

[b] Zagoskin, L. A., Travels on foot and description of the Russian possessions in America from 1842 to 1844: Ermans Archiv für wissenschaftl. Kunde von Russland, vols. 6 and 7.

A later impetus to exploration was given when in 1863 the Western Union Telegraph Company undertook to build a telegraph line through Alaska to connect the settled parts of America and Europe. In 1865 Kennicott, who was in charge of the scientific work of this company, crossed the Kaltag portage and surveyed the route to Nulato. During the same year J. T. Dyer and R. D. Potter, according to Dall,[c] made a very hazardous and successful exploration of the country between Norton Bay and the mouth of the Koyukuk River on the Yukon. Unfortunately no map of this trip was published, and the data collected, although undoubtedly used by Dall,[d] have never been available. In 1865, also, another party under the leadership of Baron von Bendeleben explored the route for the line from Norton Bay to Port Clarence, but the results like those of the other parties have never been published.

The death of Kennicott in 1866 caused the leadership of the scientific corps to pass to W. H. Dall. It was the work accomplished while in charge of the telegraph exploration and during the year succeeding the abandonment of the enterprise that enabled Mr. Dall to write the most authoritative general book on Alaska that had appeared up to the time of the discovery of valuable gold deposits. All branches of geography and geology received some attention from this investigator and many of his observations will be quoted in more detail in subsequent portions of this report.

A period of ten or fifteen years elapsed during which few notes of value were collected and published concerning the Nulato-Council region. In 1885 Lieutenant Allen made his famous trip, during which a portion of the Koyukuk was mapped and also the portage from Kaltag to Unalaklik. About this time explorations by the Revenue-Cutter Service were begun. The explorations of this branch of the government service which directly concerned the Nulato-Council region were by Purcell in the vicinity of Selawik Lake and by Zane along the Koyukuk to Nulato.

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[a] Seeman, Berthold, Navigation of H. M. S. *Herald* during the years 1845–1851, vol. 2, London, 1853, pp. 119–120.

[b] Op. cit., pp. 130–148.

[c] Dall, W. H., Alaska and its resources, p. 357.

[d] Op. cit., map.

In 1889 Prof. I. C. Russell[a] ascended the Yukon, and his report of this trip furnished many facts, both of geologic and geographic significance.

With the discovery of gold in the Klondike an influx of prospectors and others into Alaska followed, and soon afterwards the United States Geological Survey was able actively to undertake geographic and geologic investigations of the district. One of the earliest of these surveys was conducted by Spurr,[b] mainly in the basin of the Kuskokwim. The geologic and topographic map published with his report covers the area between the Koyukuk and the Koyuk and from the mouth of the Kateel southward, and is consequently the first geologic map of the eastern half of the area studied in 1909. Most of the information concerning the Nulato-Council region was compiled or gathered from reports of prospectors, and very little geographic significance, outside of the distribution of the different geologic groups, was added.

Schrader[c] in 1899 came down the Koyukuk and the maps published in the report of his trip, which were made by T. G. Gerdine, afford a much more detailed representation of the region than had hitherto been available. No traverses of the country away from the river were made, so that details regarding the region between the Yukon and Norton Bay were not acquired. At the close of the field work in the Koyukuk region Schrader went to Nome and with Brooks made the first examination by Survey geologists of Seward Peninsula.

In 1900 two main parties were dispatched to Seward Peninsula. One in charge of A. H. Brooks investigated the region as far east as Council; the other in charge of W. J. Peters, with W. C. Mendenhall as geologist, investigated the southern part of the peninsula as far east as the Koyuk. The field studies of the Peters party cover the western part of the area visited by the expedition of 1909 and will be referred to in detail in succeeding pages of this report. In the main, however, the results may be summarized as follows: A delineation of the major features of the topography by maps, the publication of data on various geographic subjects such as climate, vegetation, and fauna, and the statement both verbal and graphic of the areal, historical, and economic geology.[d] The studies of Mendenhall were carried on mainly from the streams; the three larger ones, the Fish, the Tubutulik, and the Koyuk, he ascended in canoes.

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[a] Russell, I. C., Notes on the surface geology of Alaska: Bull. Geol. Soc. America, vol. I, pp. 99–162.

[b] Spurr, J. E., A reconnaissance in southwestern Alaska in 1898: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1909, pp. 31–264.

[c] Schrader, F. C., Preliminary report on a reconnaissance along Chandlar and Koyukuk rivers, Alaska, in 1899: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 441–486.

[d] Mendenhall, W. C., A reconnaissance in the Norton Bay Region, Alaska, in 1900, a special publication of the U. S. Geol. Survey, 1901, pp. 183–222.

During 1901 Schrader made a trip to northern Alaska and visited portions of the Koyukuk drainage basin.[a] In the same year Mendenhall[b] explored the Kobuk River, and although this region lies considerably to the north of the Nulato-Council area the information secured throws considerable light on the problems of the latter. In the reconnaissance by Schrader, a geologic map was published showing the different formations along the Koyukuk northwestward from latitude 66° north, and this map and the notes on the lower part of the river already referred to on page 15 afford a continuous section from the Yukon northward.

Of the other survey expeditions that have visited contiguous areas the party under Collier in 1902 and the Atwood party of 1907 are the only ones that require specific reference here. The main object of these expeditions was to study the coal resources of portions of Alaska. A publication has appeared setting forth the results of the investigations by Collier,[c] but Atwood's report has not yet been published, though many of the manuscript notes have been kindly furnished to the present writers.[d]

In 1906 a traverse from the mouth of the Koyukuk to the shores of Norton Sound and thence to Council was made by a party sent out by the War Department. The object of the survey was to determine the feasibility of a land route from the navigable waters of the Tanana to the vicinity of Council City. The maps accompanying the report of this survey were the first to give accurate information concerning a strip of country 5 to 10 miles wide extending from the mouth of Koyukuk to the mouth of the Koyuk, and are replete with facts of geographic interest. J. L. McPherson was in charge of the field work and prepared the text of the report.[e] Specimens of the various formations crossed were collected and submitted to the United States Geological Survey for study. On this account it was not necessary to cover the area surveyed by McPherson's party again when the Nulato-Council region was visited in 1909. Reference to this report will be made in more detail in subsequent pages of this paper.

In 1908 A. G. Maddren made an exploratory survey of Innoko River and contiguous areas. His report on this trip, with the accompanying maps, affords considerable information concerning the country south of the Yukon. Practically all the features shown on Plate V south of the Yukon were taken directly from his maps.[a]

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[a] Schrader, F. C., Reconnaissance in northern Alaska in 1901: Prof. Paper U. S. Geol. Survey No. 20, 1904, 139 pp.

[b] Mendenhall, W. C., Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska: Prof. Paper U. S. Geol. Survey No. 10, 1901, 68 pp.

[c] Collier, A. J., Coal resources of the Yukon, Alaska: Bull. U. S. Geol. Survey No. 218, 1903, 71 pp.

[d] Atwood, W. W., Geology and mineral resources of parts of the Alaska Peninsula: Bull. U. S. Geol. Survey No. 467, in preparation.

[e] McPherson, J. L., Reconnaissance and survey for a land route from Fairbanks to Council City, Alaska: Sen. Doc. No. 214, 59th Cong., 2d sess., 1907, 22 pp., 7 maps, 6 plates.

GENERAL TOPOGRAPHY.

Throughout the Nulato-Council region the relief is relatively low. Few hills over 3,000 feet occur and the larger part of the upland area is only about 2,000 feet above sea level. Although there are no high ranges, steep slopes lead from the flat river bottoms to the highlands. In the Nulato-Norton Bay region there are numerous parallel northeast-southwest ridges, the highest of which forms the divide between the Inglutalik-Ungalik and the Kateel-Gisasa river basins. The hills to the north of the East Fork of Koyuk River are low and rolling, without pronounced direction. Farther west, in Seward Peninsula, there are three ranges forming prominent landmarks; these are the hills between Buckland and Kiwalik Rivers, and the Darby and the Bendeleben Mountains. The higher points of the first range rise to elevations of about 2,500 feet; in the Bendeleben Mountains the highest point is a little over 3,700 feet, and in the Darby Range the highest peak is about 3,000 feet. In the two last-named ranges precipitous slopes more than 2,000 feet high give a very rugged topography.

Outside of these three higher areas the uplands are rolling, with elevations from 1,000 to 2,000 feet above sea level, unforested, well drained, and covered with angular fragments of frost-riven waste. Pinnacles of the underlying rocks form fantastic knobs here and there.

The drainage of the region studied flows into the Yukon, into Norton Bay, into Norton Sound, or into Kotzebue Sound. The streams belonging to the Yukon drainage and to the eastern part of Norton Bay show pronounced parallelism with the geological structure, and long, narrow valleys are the result. The gradients of the main valleys are low, but those of the small side streams rise rapidly headward. In places the streams flow through narrow rock-walled canyons of slight depth, but in others flat flood plains and gravel deposits occur. In the headward portions of the basins complex relations of the streams on opposite sides of the divide are noted, and it is by no means possible at long range to foretell the direction of the drainage. In Seward Peninsula, where the geologic structure is more complex, the effect on the streams is not well marked and irregular courses are the rule. In this part of the area the longer streams, such as the Koyuk, the Kiwalik, and the Tubutulik, flow more or less parallel with the mountains, but Fish River and its larger tributaries flow at right angles to the Bendeleben Range.

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[a] Maddren, A. G., The Innoko gold-placer district, Alaska: Bull. U. S. Geol. Survey No. 410, 1910, pls. I and II.

Almost all the valleys show signs of having been eroded entirely by stream action. In the headwaters of the rivers rising in the Bendeleben and the Darby Ranges, however, there are glacial cirques and valleys. Here the present streams form irregular threads on the broadly open floors of valleys with very steep sides. At the mouths of the streams flowing into Norton Bay many of the streams, instead of showing erosion features, have filled the former valleys, which have been depressed, with sand and gravel. Examples of this kind of topography are found at the mouth of the Kwik, the Tubutulik, and the Kwiniuk Rivers, where numerous lakes and sloughs form an untraversable network during the summer.

The coast line presents numerous examples of different types of shore topography. From the Reindeer Hills to the Koyuk a coastal plain, recently emerged, affords a relatively straight shore with such slight depths of water off the coast that approach for large vessels is impossible. Of course, under such conditions, harbors do not exist. On the western side of Norton Bay the sinking of the land and the attack of the waves have resulted in a rugged coast with cliffs and harbors. This part of the coast is formed by the Darby Range, which rises in abrupt slopes from the sea and forms a long southward pointing peninsula. West of this range the deep reentrant of Golofnin Sound and Bay, which probably represents the submerged portion of an old valley similar to that of Fish River, affords a good harbor. Still farther west rocky headlands with intervening beaches produce a diversity of forms. On the depressed portions of the coast there are sand spits, such as the long point extending east from near the mouth of the Kwiniuk.

DRAINAGE BASINS INCLUDED.

All the streams flowing through the Nulato-Council region may be considered as belonging to one of three main basins, namely, the Yukon, the Norton Sound, and the Kotzebue Sound. Of these the first two include by far the greater number of streams. Roughly computed about 50 per cent of the area shown on the maps, Plates I and V, is drained by the Yukon and its tributaries, 45 per cent by tributaries to Norton Sound, and 5 per cent by streams flowing into Kotzebue Sound. In the description of these different basins no attempt will be made to enumerate all the streams belonging to each, for that sort of information may be better gathered from the maps (Pls. I and V), but rather to present the particular features not easily legible on topographic maps of such scales as those adopted for publication.

YUKON BASIN.

The portion of the Yukon considered in this report extends from slightly east of the mouth of the Melozitna on the northeast to near the mouth of Kaiyuh Slough on the southwest. In this distance the main tributaries are the Koyukuk, the Nulato, the Kaltag, and the Khotol. Regarding these various streams, with the exception of the first two, no new data of geographic interest were received during 1909, and as the facts already known about the Kaltag and the Khotol are indicated on the map accompanying these reports, no further description of them will be attempted.

Kateel and Gisasa rivers formed the portions of the Koyukuk drainage that were visited and mapped, but only the upper 30 to 50 miles of each stream were seen in any detail. McPherson, who crossed the Gisasa near latitude 65° North, describes the valley as follows:[a]

> The Gisasa River is a stream from 70 to 150 feet wide, with gravelly bottom. Along the river banks on the north side of the valley is a heavy growth of spruce. Along the south side of the valley timber grows in scattered bunches, the intervening ground being to a considerable extent marshy and niggerhead tundra.

From the survey of 1909 it was found that the Gisasa Basin was a peculiar, narrow one, lying between the Nulato on the southeast and the Kateel on the northwest. The river from mouth to head near Camp A9 must be nearly 70 miles in a direct line. In this distance few or no tributaries much more than 10 miles in length are received. The basin is thus probably less than a score of miles wide in its widest part, and in the headward 50 miles it is generally much less.

As will be shown in a later portion of this report the direction and the general physical features of the Gisasa Valley are due to the geologic structure of the region, which trends northeast-southwest. Although in portions of its course the river flows on a flat gravel plain essentially at the level of the stream, in other parts it has rock walls through which the stream has cut narrow canyons. These canyons are not continuous, but appear at irregular intervals along the valley. None of the canyons are deep, only a few of the rock walls, if any of them, reaching a height of 50 feet. Above the steeply incised walls a more open valley is usually found, which indicates rather recent minor deformation of an anterior topography.

The Kateel Basin was seen in less detail by the writers, but its general features are essentially similar to those of the Gisasa, except that its valley is wider and it has longer tributaries. From the survey of McPherson it was determined that Arvesta and Caribou creeks are tributaries of the Kateel. The former, where it was crossed, near latitude 65° north, is from 50 to 70 feet wide and from 1 to 3 feet deep. The latter is much smaller and runs at an elevation about 500 feet higher. Prospectors who crossed the region somewhat north of McPherson's route state that the volume of the Kateel is much smaller than that of the Gisasa.

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[a] McPherson, J. L., op. cit., p. 17.

A general idea of the Kateel Basin was afforded by a view from Traverse Peak, though the weather was unfavorable for a thoroughly satisfactory observation of the topography. From this point it was evident that the northeasterly trend observed in the Gisasa Valley was still dominant. The divide along the western margin of the basin ran nearly north and south, so there is a considerable area tributary to this river. Low passes lead from the Kateel into the Ungalik, or into the Inglutalik, and probably into the Buckland. The pass from the Kateel to the Buckland was not actually seen, but enough of the drainage arrangement was evident to show that some of the western tributaries joining the Kateel below its junction with Arvesta Creek head in the low hills east of the Buckland, so that an easy route undoubtedly exists between the two rivers.

The Nulato River Basin is long and narrow, being formed by two large streams occupying strike valleys that coalesce a few miles from the Yukon and below this point are transverse to the structure. The main branch is about 50 miles long in a straight line. Its valley has a broad gravel-filled floor on which the stream meanders in irregular pattern. It will be seen from the map of this valley that, although lying parallel with the Yukon and not more than 20 or at most 25 miles away from that stream, it drains northeastward, whereas the Yukon in that part of its course flows southwestward. This results in a more than right-angled turn near the mouth of the Nulato, and suggests that the physiographic development of the streams has been complex. Smooth slopes rise steeply from the valley floor to the relatively even uplands. On the southeastern side high hills scored by narrow gulches preserve the snowfall late in the summer. The volume of water carried by the main branch is therefore more constant throughout the season than is the case of those streams dependent upon the rainfall. Passes easily traversable by horses lead from the Nulato Basin to that of the Gisasa, of the Shaktolik, and probably also of the Unalaklik.

NORTON SOUND DRAINAGE.

TRIBUTARIES OF NORTON SOUND EAST OF KOYUK RIVER.

East of Koyuk River the main streams belonging to the Norton Sound drainage from south to north are the Unalaklik, the Shaktolik, the Ungalik, and the Inglutalik. All of these rivers show pronounced angular bends on a large scale, most of which are to be accounted for by the geologic structure of the region. This condition is best illustrated by the three northern streams, whose basins are almost completely mapped. It will be seen from the map that for the first 5 or 10 miles[a] in a straight line from the coast the rivers flow in winding courses at a right angle to the shore. Upstream from this point the course abruptly changes, and for the next 10 to 30 miles the rivers have a nearly north-south trend. Still farther upstream the direction again changes, and the streams flow from the northeast or even from the east-northeast.

Taken as a whole, the three rivers have narrow, rather contracted basins in the middle or north-south part of their courses, because few tributaries enter from the east and west; in the upper part, however, because the main streams are flowing more or less across the geologic structure, the side streams are long and the area tributary to the main streams is therefore more extensive. Rock-walled canyons, separated from each other by gravel-filled basins, bear witness to recent crustal movements throughout the area.

Unalaklik River was not visited by the survey party in 1909, but portions of it are well known, because the portage from the Yukon to St. Michael follows the lower part of this stream. A long branch joining from the north heads against the Shaktolik River, and it is probable that an easy pass across the hills to Nulato River exists. The northeast-southwest trend of the drainage and the intricacy of stream arrangements make it difficult to interpret the topography at long range. It is possible, therefore, that the Shaktolik may extend farther around the head of Nulato River than was evident at a distance, so that there may be more than one divide between Nulato and Unalaklik rivers.

North of the Unalaklik is a rather small stream, the Iguik, which drains the triangular area between the Unalaklik and the Shaktolik. Its drainage basin is at most only a few hundred square miles in area.

Although previously mapped as a rather unimportant river, the Shaktolik drains a considerable territory between the Ungalik on the north and the Unalaklik on the south. Its course is so irregular that it can with difficulty be recognized at any considerable distance. The Shaktolik was first seen in detail near camp A10. At this place its course was nearly due north, giving the impression that it flowed northward into the Ungalik. Near camp A13, however, it joined with a branch from the south and formed a good-sized stream. From the small increase in the size of the northern branch between camp A10 and its junction east of camp A13 it seems certain that only a few tributaries enter between these two places.

Near camp A10 the river is incised in a narrow rock-walled canyon about 30 feet deep. Above the canyon walls the topography opens out into a broad older valley which had reached maturity before the uplift took place by which the present cycle was started. The floor of this older valley is in large measure rock cut with a relatively small amount of gravel covering. Well-rounded material, however, is practically universally present and affords indisputable proof of the presence of stream erosin at this higher level. Near camp A13 the canyon-like character is wanting. Four or 5 miles below camp A14 incised meanders, with radii of from one-half mile to 1 mile, occur. Here the walls are, for the most part, gravel, with the bedrock not exposed. It is believed that the differences in the amount of filling and incision noted along this stream are due to the undulatory character of the most recent uplift.

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[a] The figures given represent measurements in an air-line and not along the circuitous courses of the streams.

No accurate determinations were made of the volume of the Shaktolik, but from float measurements near camp A12 it was found that the discharge was between 150 and 200 second-feet. The tributary from the north joining east of camp A13 was of about equal volume, and below camp A14 the amount of water had increased to such an extent that the stream could be crossed only with difficulty. In this connection it should be noted that 1909 was an exceptionally dry season, so that a greater volume is to be expected during a year of normal precipitation.

Ungalik River shows the same characters as the other streams tributary to Norton Bay from the east. Its basin shows the three distinct parts previously referred to, namely, an open east and west course through the coastal plain province, a narrow north and south portion parallel to the geological structure of the region, and a northeast and east-northeast course in the headward portion. In this upper part the basin shows the same feature previously noted on the Shaktolik, namely, that the tributaries from the south are longer than those from the north, so that the basin, if the main stream be considered as its axis, is decidedly unsymmetrical. This lack of symmetry seems to be due to three causes, namely, structural control, climatic conditions, and tilting. Asymmetrical valleys are common in Alaska, and have previously been described by different authors. An epitome of the various causes with reference to a specific region has been published by Goodrich.[a] It was pointed out by this geologist that the effect of insolation differs according to the condition of the stream as to load; thus, if the stream is overloaded, the tendency will be for the waste to push the stream toward the side receiving the least sun, whereas, if the stream is not carrying all the material it can the reverse tendency will dominate, and the stream will migrate toward the side receiving the most sun. Plate II, *A*, shows one of the tributaries of the Shaktolik below camp A12, which is migrating toward the north because the stream is underloaded and the south-facing slope receives more warmth than the

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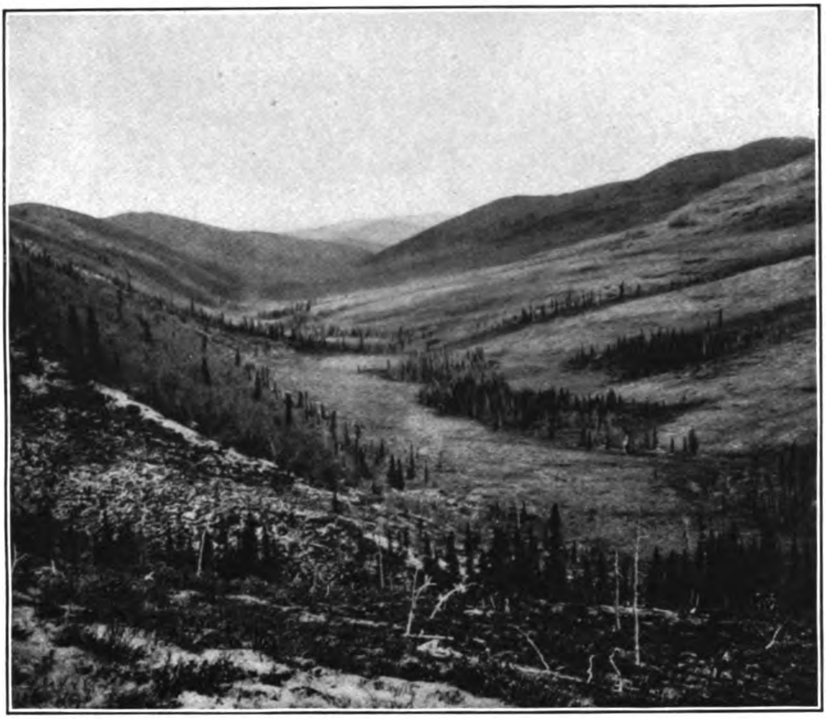
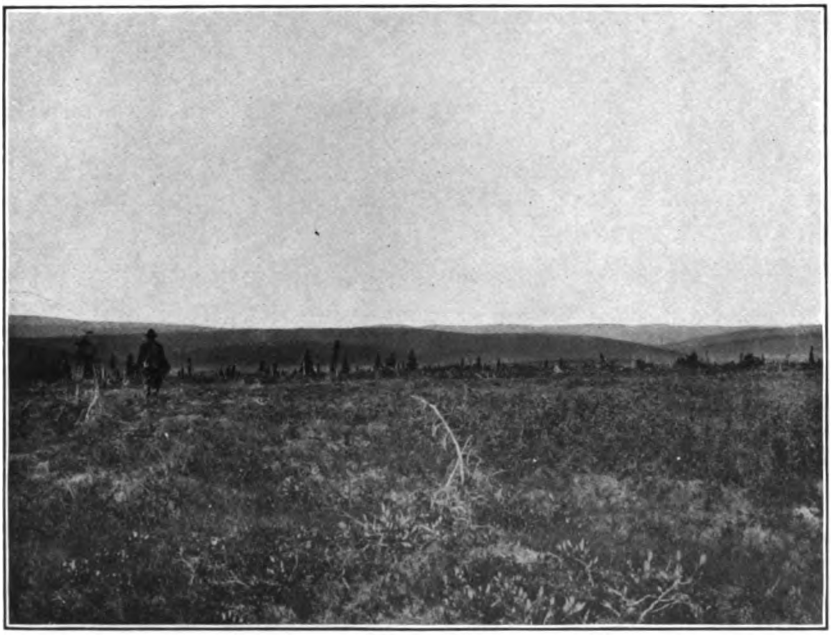
[a] Goodrich, H. B., Cause of asymmetry of streams: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, pp. 285–289.



A. ASYMMETRIC VALLEY, SHAKTOLIK BASIN.



B. UPLANDS BETWEEN EAST FORK AND INGLUTALIK RIVER.

other. In a consideration of the development of the drainage it should be borne in mind that types due to one cause alone are practically absent and that complexity of origin, rather than simplicity, is normal.

From Ungalik River passes may be found into the Inglutalik to the north or to the Kateel on the east, or into the Shaktolik on the south. None of these passes are over 3,000 feet above the sea, and many could be found at elevations below 2,500 feet. The saddle by which McPherson crossed from the Kateel to the Ungalik was only a little over 2,000 feet.

As regards size, the Ungalik is not so large as the Shaktolik. Two miles below camp A16 the stream could be crossed in less than 2 feet of water, and farther upstream it was still shallower except for occasional deep holes. Lower downstream, however, in the coastal plain portion of its course, it becomes deeper and sluggish, and instead of a hard gravelly bottom it has a soft mud bottom that makes crossing difficult without a boat.

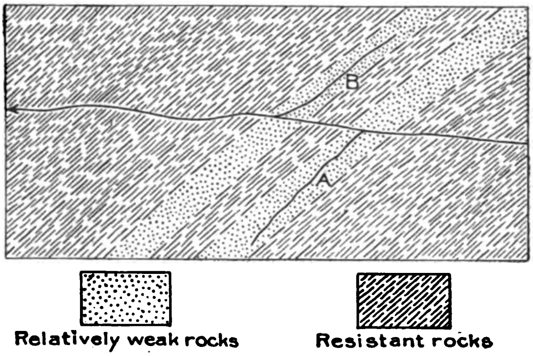


FIGURE 2.—Arrangement of drainage due to geologic structure.

Inglutalik River derives its name from the Eskimo words meaning "river of bones," in reference to the number of mastodon and other bones found in the terrace of gravels along its course. It is at least 60 miles long and appears to have a greater volume of water than either the Shaktolik or the Ungalik. Below camp A18, in the coastal plain province, the river can not be forded; at camp A18 is the first riffle, and on it good crossing in about 2 feet of water is afforded. Poling boats have been taken as far as camp B9, and during seasons of normal precipitation could undoubtedly be worked still further upstream.

In the upper part of the Inglutalik Basin the drainage is very complex, and many readjustments have taken place, so that at a distance of 5 or 6 miles it is impossible to tell whether the river drains toward the north or the south. Backhand or barbed drainage is common. It should be noted, however, that this feature is not always to be accounted for by capturing, but in many instances is due to the geological structure. Figure 2 indicates in diagrammatic manner how a normally developed subsequent stream (A) may have a barbed junction with the main stream without capturing having taken place. In this same figure stream B is also a normally developed subsequent stream, but as the soft bed on which it has developed forms an acute angle with the course of the main stream the tributary enters without the barbed junction.

Low passes easily traversed by horses lead from the Inglutalik into the Kateel basin to the northeast; into the Ungalik on the south; into the Koyuk on the west; and into the Buckland on the north. It is reported, although it was not confirmed by personal observation, that part of the Selawik drainage also heads against the Inglutalik. There are no known facts which would make such a condition unlikely, but the region in question is so entirely unexplored that conjectures as to the drainage are hardly warranted. The only information on this subject is Zagoskin's trip up the Kateel to near the big bend, in 65° 30′ north latitude. According to this traveler a low pass leads from near this point northwest to the Buckland. It should be realized, however, that Zagoskin did not attempt the passage; that there may have been a misunderstanding as to the river on the western side of the divide, and that it is possible his informants were not correct in their geography. From the present status of knowledge it seems more likely that a pass northwest of the big bend of the Kateel would lead into a north-flowing branch of the Selawik than to a west-flowing branch of the Buckland.

KOYUK RIVER.

Koyuk River enters the northern reentrant of Norton Bay and is a river over 80 miles long. For the first 15 miles from the mouth it has a nearly southerly course, but above this point it flows more or less directly from the west toward the east. For 60 miles or so its tortuous meanders make measurements along the river many times the air-line distance. Mendenhall and Peters in 1900 traversed the river as far west as the head of canoe navigation a few miles above Knowles Creek, and the details of their map have been taken for the course of this stream. In 1903[a] Moffit and Witherspoon, mapping the northeastern part of Seward Peninsula, added many facts concerning the Koyuk basin north of the main stream and concerning the river itself beyond the point reached by Mendenhall and Peters in 1900.

From the observations of the earlier geologists and topographers, supplemented by the field work of 1909, it appears that the Koyuk basin is unsymmetrical. Of the various tributaries, East Fork undoubtedly drains the largest territory. Its basin is about 30 miles long, heading against portions of Buckland and Inglutalik river basins. Many low passes lead from the East Fork basin into the

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[a] Moffit, F. H., The Fairhaven gold placers, Seward Peninsula: Bull. U. S. Geol. Survey No. 247, 1905, pls. II and III.

Buckland. Probably the lowest pass is by way of the branch on which camp B12 was located. The elevation of this camp was approximately 300 feet above the junction of East Fork and the Koyuk, and as there is a strong upstream current, due to the tides, as far as the mouth of Peace River, it is safe to assume that the mouth of East Fork is practically at sea level. North of camp B12 there is a broad abandoned valley in which there are several lakes. Some of these drain northward and some southward. The elevation of these lakes is not more than 100 feet above the camp, so it is certain that there is a route across Seward Peninsula from Norton Sound to Kotzebue Sound, nowhere more than 400 feet above sea level.

TRIBUTARIES OF NORTON SOUND WEST OF KOYUK RIVER.

West of Koyuk River the main tributaries of Norton Sound from east to west are Kwik, Tubutulik, Kwiniuk, and Fish rivers. All of these streams are mainly within the area occupied by metamorphic rocks of complex structure and consequently do not show by their courses the striking structural control noted in the rivers farther east. Because of the greater amount of information available concerning the region west of the Koyuk, the map of southeastern Seward Peninsula (Pl. I) shows the distribution and character of these rivers in greater detail than was possible on the smaller scale map adopted for the Nulato-Norton Bay region (Pl. V).

Kwik River is a small stream about 20 miles long flowing in the main on a very flat slope in a circuitous course in a gravel-filled basin. It heads in the divide between Norton Bay and the east-west portion of the Koyuk. Passes lead across this divide at low elevations. The lowest pass is by way of the branch on which camp C4 was located. At this point a broad, open saddle at an elevation of only a little more than 600 feet affords an easy route from one basin to the other. The most characteristic feature of this basin is the flat lowland through the lower three-quarters of the area and the short, rather steep gradients of the streams above the point where they enter the flats.

Tubutulik River had previously been traversed by Mendenhall and Peters, so that few notes concerning the stream arrangements were collected in 1909. In the main this basin is parallel with the igneous intrusions of the Darby Range, but above Lost Creek, where the granites disappear, the course for several miles is more nearly east and west. Above this point its general direction is north and south. In this part of its course is a lowland, locally known as Death Valley, which is elliptical in outline and about 7 miles long by 5 miles wide. North of Death Valley the headwater streams rise in the high eastern extension of the Bendeleben Mountains and flow on steep gradients into the Death Valley Basin. The lower 5 to 10 miles of the Tubutulik basin is formed by swampy lowlands similar to those at the mouth of the Kwik. In fact, the area between the lower portions of these streams is practically undivided, and it would be almost impossible to determine just what portion of the flat was tributary to one stream and what to the other.

Measured in a straight line from its head to its mouth, the Tubutulik is about 40 miles long, but its numerous meanders make the distance along the river much greater. Several low passes lie between the Tubutulik and the Kwik on the east, the Koyuk on the north, and the tributaries of the Fish on the west. The ridge between the Tubutulik and the Kwik nowhere exceeds 1,000 feet, so that at the heads of the tributaries are many places where passages at elevations of 600 to 800 feet may be found. Between the Tubutulik and the Koyuk there are two low saddles where the elevation does not exceed 1,000 feet. The most important of these saddles is the one east of Death Valley, where the trail from Nome to Candle crosses the divide. At this place the elevation is only a little more than 800 feet above sea level. The low saddle is north of the north fork of the Tubutulik and leads into Timber Creek, a tributary of the Koyuk. This pass is broadly open and has several small lakes scattered on the flat divide. Between Tubutulik and Fish rivers there are two or three low passes, but the one taken advantage of by the telephone lines is perhaps the lowest. North of this one, however, near camp C8, there is a saddle at an elevation of about 1,000 feet, by which horses can easily cross from the Tubutulik into the Fish River basin.

Southwest of the Tubutulik the Kwiniuk River drains an area of approximately 100 square miles. It has an extremely irregular course, its bends in the main being dominated by the general north-south geologic structure. It has many side streams joining it in back-hand manner. This is especially true in the portion around camp C14. About 2 miles south of this point there is a long tributary coming in from the west which makes a sharp bend and cuts across the prevailing structure to join the Kwiniuk; 2 miles north of camp C14 also there is a stream flowing almost due south until it enters the northeastward-flowing Kwiniuk. It is believed that some of these abnormal features may be explained by the obstruction of the drainage by deposits formed by valley glaciers from the Darby Range, which have prevented a former direct course to the sea.

The Kwiniuk basin is about 30 miles long and is on the whole rather narrow. In places rock walls constrict the river, but in other places there are gravel-filled basins of small extent in which the river splits into many separate channels. At the mouth, the river flows on the broad gravel deposits (which probably represent basin filling) that merge with the flats at the mouths of Tubutulik and Kwik rivers. In this part of its course the basin is characterized by an intricate network of sloughs and channels impossible to traverse in summer.

Fish River is the largest stream west of the Koyuk. Between it and the Kwiniuk many streams heading in the north-south Darby Range flow in short courses eastward into Norton Sound or westward into Golofnin Sound. Fish River, like the Koyuk, was ascended by Mendenhall and Peters in 1900, and the form of the main river has been taken directly from their map. It is an extremely tortuous stream in its lower and middle course, but in its headward part and for a short distance in the so-called Fish River gorge it is an actively degrading stream. In the lower part the river splits into numerous distributaries on the delta, and its flow is so sluggish that it is difficult to distinguish the main channel from blind sloughs. Steam river boats ascend the river as far as White Mountain, but above this point as far as Council, on the Niukluk, or as far as Mosquito Creek, on the main river, horse boats are used.

Above the junction of Niukluk and Fish rivers the valley of the main stream is constricted and the river flows through a gorge with rather steeply sloping walls for a distance of about 10 miles. Upstream from the gorge the valley opens out and the floor is a flat gravel-covered plain 15 miles wide parallel with the direction of the stream and 30 miles long transverse to this direction. This part of the basin is an unexplained physiographic feature. The plain is dotted with lakes and sloughs slightly sunk below the general level of the surface. Here and there, irregularly distributed, are low gravel mounds from 10 to 50 feet in height, that seem to mark former deposits so dissected that perhaps not one-hundredth of their original extent is preserved.

The main tributaries from the west are Niukluk and Pargon rivers. The former rises in the Bendeleben Mountains and the hills to the south about 20 miles west of the mapped area. The Pargon, sometimes incorrectly called the Parantulik, rises in the high east-west range which forms the eastern extension of the Bendeleben Mountains. It flows along the southern margin of the Fish River basin for nearly 20 miles before entering the main stream. From the east the main tributaries of Fish River are, from south to north, Etchepuk and Rathlatulik rivers and Mosquito Creek. All of these rise in the high Darby Range that forms the eastern border of the Fish River basin. In their headward portions they all flow in rather youthful valleys with fairly steep gradients, but as they cross the flats their slopes decrease, and they flow in sinuous courses slightly incised below the level of the plain.

KOTZEBUE SOUND DRAINAGE.

The only portion of the Buckland or other Kotzebue Sound drainage seen was between camps B5 and B13. In this region only the headward part of some of the streams belonging to the Buckland were observed near at hand, and therefore few additional data as to the larger features of the basin as a whole were obtained. It seems, however, that the area of this basin has been in large measure exaggerated. From the mouth of the Buckland to the divide between that river and the East Fork of the Koyuk in a straight line the distance is between 50 and 60 miles, and from the mouth to the divide near camp B5 is only a little over 60 miles.

Like many of the other basins which have been carved mainly on bedded sediments of Mesozoic age in this part of Alaska, the basin of the Buckland tributary streams shows pronounced structural control. This results in an irregular distribution of narrow valleys parallel to the geological structure of the region, with transverse gorges. In this kind of topography the recognition of the true direction of the drainage from a distance is almost impossible. The western branch of the Buckland, visible from Bear Creek (north of camp B13) flows in a broad, flat valley, the average gradient of the stream from mouth to head probably not exceeding 6 to 8 feet a mile. In the descriptions of Quackenbush[a] and of the earlier surveys by Captain Kellett and other officers of H. M. S. *Herald* and *Plover*, it is stated that the Buckland is navigable in light boats for about 60 miles as measured along the river's course, that is, as far as the forks of the stream about 20 miles north of the Koyuk-Buckland divide.

The low pass from Buckland to the east fork of Koyuk River has already been described. A pass from the Buckland into the Kiwalik basin by way of Bear Creek has been utilized by a road from the mining camp on Bear Creek to Candle. The divide between the Buckland and the Inglutalik is low, and, although usually covered with dense brush, it offers no considerable obstruction to crossing from one drainage basin into the other.

UPLANDS.

As has already been stated, the relief in the Nulato-Council region is relatively low. Few hills are more than 3,000 feet high, and the larger part of the upland is probably not more than 2,000 feet above sea level. There are, therefore, but small differences in elevation between the uplands and the lowlands and still less between different portions of the upland. This results in producing a sky line uninterrupted by any considerable inequalities.

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[a] Quackenbush, L. S., Notes on Alaskan mammoth expeditions of 1907–8: Bull. Am. Mus. Nat. Hist., vol. 26, 1909.

Smooth, rolling uplands are particularly characteristic of the East Fork-Inglutalik divide. In this part of the field the features are slightly dissected, rounded domes, with gentle slopes merging with the present valley walls by a series of benches. Plate II, *B* (p. 22), shows a typical portion of this upland and is characteristic in a broad way of the divides between most of the minor drainage basins. On such uplands traveling is good, as the surface is well drained and the frost-disintegrated fragments afford good footing. Not only are uplands of this type found in the regions where unmetamorphosed sedimentary rocks form the bed rock, but they are also characteristic of parts of the schist region—as, for instance, at the head of Kwik River.

Even the higher and more rugged divides here and there show a somewhat flat-topped character. Thus, on both sides of the Koyuk-Buckland lowland there are numerous flat-topped hills, some a mile or so in width, carved on materials very different both in composition and in apparent resistance to weathering. This feature is also seen in the hills north of Death Valley on the Tubutulik. On one of these hills north of camp C7 a profile similar to figure 3 was observed which showed at least five flats from a quarter to half a mile wide. These have been produced on a complex structure of schists, thin limestones, and granites.

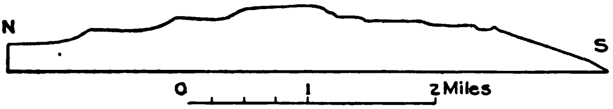

FIGURE 3.—Profile of hill north of camp C7, at head of Tubutulik River.

The two main mountainous regions are (1) the divide between the Yukon and the Norton Bay drainages, called by McPherson the Brooks divide, and (2) the Darby and Bendeleben mountains. In the former the general trend is north and south, with the highest points only little more than 3,000 feet in elevation and the average much less. Conical peaks rising 500 to 800 feet above their neighbors afford easily recognizable landmarks, visible for long distances. A few steep, rocky crags were seen, but all are easily scalable. In the Darby and the Bendeleben mountains the trend of the former is predominantly north and south and of the latter east and west, so that together they form a crescentic highland area. The crest line of this range is ragged and irregular, being in places close to the north and west side of the range and at others close to the south or east side. Here and there the crest line is so narrow that passage even on foot is hazardous, and blocks of waste disturbed in passing roll hundreds of feet down the slope before finding lodgment. This is true particularly of the Bendeleben Mountains, where glacial action of the alpine type has been effective in the past. In certain parts of the Darby Range also this same agency has produced similar uplands. Plate III, *A*, shows a portion of the Darby Range much dissected by glaciation and illustrates the narrow pinnacled character of the upland that results. Such divides are not due to valley glaciers having covered the upland, but are the result of headward erosion on opposite sides of the ridge.

Regarding the origin of the uplands, there has been no clear evidence found to indicate the effective causes. As will be explained in detail later, it is known that the deformation which took place after the deposition of the Cretaceous sediments was so great that any topography formed prior to this event must have been so changed as to have little or no effect on the present topography. The surface therefore has been formed between the Eocene and the present time. It is known that none of the mountains indicated by the dips of the strata formed by the folding are preserved at the present time in this region. The upland surface has therefore been produced by erosion, and the present hills owe their height rather to greater resistance to erosion than to original constructional uplift. Whether this erosion resulted in a nearly plain surface approximately at sea level, which has subsequently been uplifted and again dissected, or whether the erosion took place at considerable elevations above sea level and leveled without base leveling the tops of the hills, is a question that must await much fuller investigation. There are the following objections to the interpretation that the present upland surface represents a formerly nearly base-leveled surface subsequently uplifted—the absence of any water formed deposits on the surface of the upland; the lack of deep-rock weathering; the number of flats separated from each other by sharp scarps similar in all characters to the uppermost one, which require similar explanations; the absence of drainage arrangement that would correspond to the hypothetical earlier surface; the indications that present-day processes are responsible for leveling without base leveling. On the other hand, the main objection to the idea that the upland does not mark an old erosion surface nearly at base level is the lack of known processes capable of producing a nearly plain surface on rocks of different resistances to erosion. It seems wise therefore to suspend judgment as to the origin of the uplands, as further information is required before their genetic classification can be effected.

COASTAL FEATURES.

Soundings made by the Coast and Geodetic Survey[a] and others have shown that nowhere in Norton Bay and Sound within the areas represented on Plates I and V is there a depth of water exceeding

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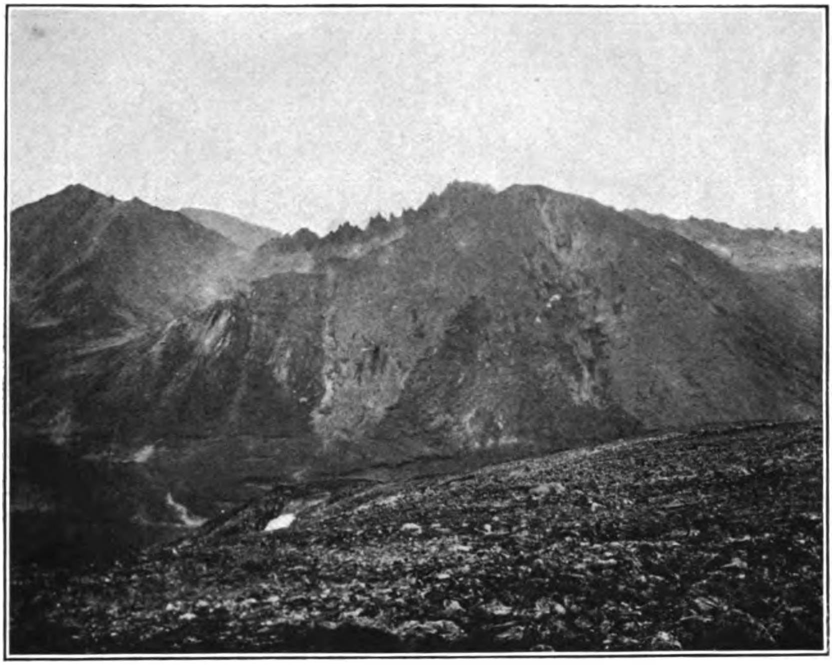
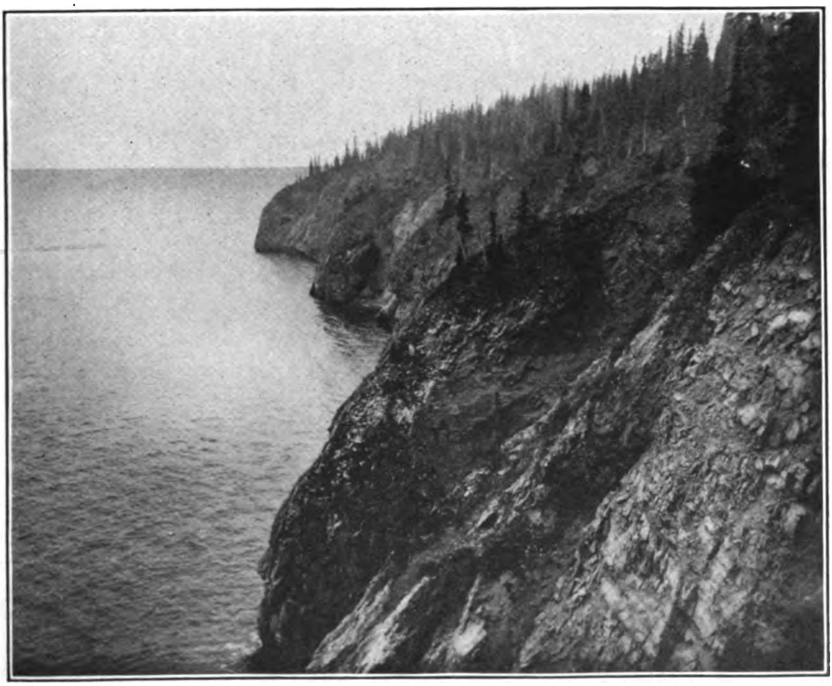
[a] See chart 9380 of the Coast and Geodetic Survey, edition of 1908.



A. CHARACTERISTIC MOUNTAIN TOPOGRAPHY, DARBY RANGE.



B. EAST COAST OF DARBY PENINSULA.

100 feet, and over much of this water area the depth averages about 50 feet. In general the 5-fathom line lies several miles from the coast, so that vessels find no harbors and have to discharge cargoes on lighters. A few exceptions to this rule occur, most notably along the east side of the Darby Peninsula and at Golofnin Sound. At the former locality the coast is rocky and landing places for vessels of sea-going size are wanting. Plate III, *B*, shows a typical portion of the eastern coast with the waves beating directly on the cliffs and with a beach so slightly developed that it is impossible for a man to walk around the shore. With such topography it is evident that shelter for vessels is wanting.

Golofnin Bay, on the other hand, presents a fairly good harbor for vessels drawing less than 20 feet, as it is sheltered by high hills from the strong winds. The channel, however, is crooked and the bay is constantly filling up with the detritus brought down by Fish River. Ocean-going vessels from Seattle call at this place irregularly during the season and discharge cargoes near the mission on lighters. Without recourse to dredging, however, this harbor would be of slight value in the general economic development of the region. It is, moreover, some distance from the productive gold areas and so is not much used, although during the boom days of the Council region it gave promise of being important and even now it is the gateway by which most of the supplies for Council and vicinity enter the country.

Kotzebue Sound on the northern shores of Seward Peninsula is also a relatively shallow sea, few if any places having a depth of 100 feet. One of the latest incidents in the geology of the region was a slight depression of the land, so that the submerged lower courses of some of the larger streams afford shelter for light-draft vessels. The shallowness of the basin as a whole and the crooked and constantly changing channels leading to these harbors make navigation difficult.

Tides in Norton Sound are relatively slight in their range but increase toward the bay heads. No accurate measurements of the tides have been made in this part of the region, and as the wind has a considerable effect on the change of water surface it is impossible to make any short-period observations of value. It is probable, however, from determinations made at Nome, that the tides seldom have a range of more than 2 feet along the east side of Darby Peninsula. Judged by the way in which the Koyuk was backed up by the tide near camp A20 the tidal range near the head of Norton Bay probably exceeds 3 feet.

As has been already noted, lagoons are found along portions of Norton Sound. These owe their formation mainly to shore currents blocking the mouths of streams. Sand reefs, such as occur near Solomon and at many other places in western Seward Peninsula, are absent in the area studied. Many of the lagoons are filled with drift timber, a good deal of which has doubtless been brought down by the Yukon and cast upon the shore by the currents.

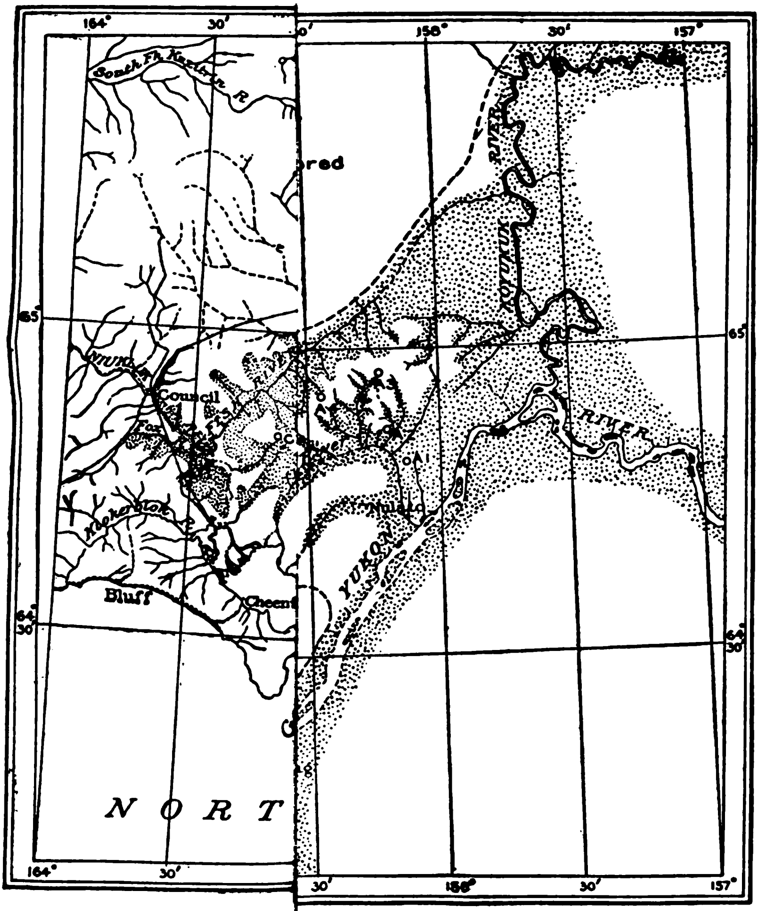
The currents are complex and have been determined mainly by the effect they have exerted on the land forms. Near the mouths of the Kwiniuk and the Tubutulik the long spits with their free ends pointing east give clear evidence that the currents there are flowing from west toward the east, but, south of camp C17 for 4 or 5 miles the apparent direction is southwest. At Carson Creek, however, the general direction seems to be northeast. On the east side of Norton Bay, near the mouth of the Inglutalik, the shore forms seem to have been made by currents flowing toward the north, whereas near Island Point the dominant current seems to divide, the southern part flowing southward and the northern part northeastward. From the south end of the Reindeer Hills the long south-pointing sand spit seems to show that the direction of currents there is in general southward.

VEGETATION AND GAME.

As the main object of the expedition of 1909 was to acquire information concerning the geology of the region traversed, little attention was paid to extraneous matters. A few notes on the general character of the vegetation and game may, however, be included.

Of the evergreen trees spruce is the only one of sufficient importance to be considered. The trees seen probably average 10 to 12 inches in diameter. Spruce extends as far west as Council, but beyond this point is practically wanting. In the eastern part of the area, near the Yukon, it grows at elevations close to 2,000 feet, but farther west, toward Norton Bay, at lower elevations, so that west of the Brooks divide it is seldom found above 1,000 feet. West of the Koyuk it rarely is found above 800 feet, and only in the valleys along the streams. In the western part of the Fish River drainage basin, spruce does not grow on any of the streams north of Mosquito Creek. Spruce is found along the eastern coast of Darby Peninsula up to elevations of about 800 feet, but west of the range it seldom grows at more than 500 feet above the sea. Plate IV shows the general distribution of timber in the region.

Birch, used by the natives for sled frames and similar gear, is found in many places in the Yukon basin, but it gradually disappears farther west until the last birch seen on the Koyuk was near Kenwood Creek and the last sizable trees in the Darby Peninsula were on the eastern slopes of Mount Kwiniuk and on the lower slopes of Mount Kwiktalik or Haystack Mountain. White birch is found in the Yukon basin, but does not occur notably to the west of this area. The Seward Peninsula birches are the yellow and the black birch. The low pros-


164°
30'
30'
158°
30'
157°
65°
65°
64° 30'
64° 30'
South Fk.
R.
red
NIUKLUK
Council
Bluff
Cheen
N O R T
YUKON
RIVER
RIVER
Nulato
164°
30'
30'
158°
30'
157°

trate birch, which has little or no fuel value, is much more widely distributed and can be found throughout Seward Peninsula.

Willows are common along almost all the Seward Peninsula streams. The willows are of several different kinds, from prostrate varieties to trees 8 or 10 feet in height, the latter being the main source of fuel throughout the western portion of southeastern Seward Peninsula. Alders are most numerous along the eastern shore of the Darby peninsula, where they form a dense undergrowth of half recumbent interlocking branches, through which passage can be effected only by chopping a trail.

No statement of the vegetation would be characteristic without mention of the abundant berries, which grow mainly above the tree zone. Blueberries are particularly prolific, the low bushes forming in places a mat of vegetation. Salmon berries, much prized by natives and prospectors, grow under essentially the same conditions as blueberries and are especially abundant on rolling low uplands, such as those between the Buckland and East Fork of Koyuk River. Currants are found, but are not abundant.

Several kinds of grasses and forage for horses are found and are generally sufficiently plentiful, so that they do not have to be specially sought until late in the season. The pack horses used by the Survey party were particularly fond of the so-called "goose grass," a kind of equisetum that grows on well-drained areas near the banks of the streams where trees do not form a thick shade. By the first of September frosts so impair the vitality of the grasses that forage must be sought with care in the protected valley heads facing south, and it becomes necessary to place camp with considerable thought as to the feed supply.

Flowers are abundant and give brilliancy to the landscape in the spring and summer. Some fifty varieties were noted, but no collections were made, and therefore no specific determinations were possible. The general impression, however, was that flowers were abundant, but that they were limited to relatively few genera and families.

Birds and animals are fairly abundant throughout the region, although they are not so plentiful that game can be relied on for food. In the higher hills between the Yukon and Norton Sound numerous caribou signs showed that the mosquitoes had driven these animals into the highlands during the early part of the summer. Farther west caribou are almost entirely wanting, although probably a few may still be found in the unfrequented region north of the Koyuk. Domesticated reindeer, held either by government or private ownership, are herded near the mouth of the Shaktolik and south of Cheenik. These herds are moved from place to place, and sometimes the animals stray away and become wild.

Bears are comparatively numerous in the less frequented parts of the region. Well-trodden bear trails run along the Shaktolik for many miles, where the animals fish during the salmon season. Along the ridge between Kwik and Tubutulik rivers, also, bear signs are abundant, especially while the blueberries are ripe. In the upper part of the Kwiniuk basin near camp C14 the sand bars are covered with bear trails. From the reports of prospectors and trappers it is said that most of the bears are rather large and brown, few black bears being found. The only bear that was seen by the Survey party was a very light brown.

Caribou and bear are the only two large animals in the region but there are several small animals that are caught either for their fur or as food. A few rabbits are found in Seward Peninsula, but none were seen in the Nulato-Norton Bay region. Red foxes were seen, and cross foxes are reported. Some marten, muskrat, and other small skins are taken by trappers in the Yukon basin contiguous to Nulato, but the number of skins is yearly decreasing. Porcupine were seen in the Inglutalik and Tubutulik river basins. Ground squirrels common in the less-forested regions of Seward Peninsula are almost entirely absent throughout the greater part of the area east of the Koyuk River.

Of the birds, ptarmigan are perhaps the most abundant throughout the region as a whole, but they are seldom found near the coast and are yearly becoming fewer and fewer. Early in the season these birds are found hiding in the brush with their young, but later in the summer flocks of fifteen or so may be flushed in many of the blueberry patches. After the berries begin to fail and cold weather approaches, the ptarmigan move from the higher land and congregate on the sand bars of the streams. A little later they begin to gather into the large coveys so often seen after the snow has begun to fall.

Along the coast where ponds and lagoons occur ducks, geese, and other water fowl are plentiful. The southward migration of the geese in 1909 took place the last of August and the first of September, and during this time thousands of birds passed over Norton Bay. Cranes were seen, some living on the low swampy country of the coastal plain province and others apparently making their homes on the dry rolling uplands. Robins, crows, and many other birds living in more southern regions were also observed but not minutely noted. Owls, both barred and snowy, are common, and their regurgitations may be found on almost every knob that gives a lookout over the surrounding country. A few eagles and hawks were seen. Spruce or " fool " hens were especially noted in the Darby peninsula country south of the mouth of the Kwiniuk, but they are also found in many other parts of the region.

Fish are almost always plentiful and can be relied on by travelers for food. Grayling are the most common of the fish and are found in all streams of sufficient size. In length they range from a few inches to about 20 inches. They will take a fly hook at almost all times during the summer. Trout of several varieties live in the clear swift waters of the mountain streams and may be caught with a fly hook. Salmon usually run up the larger streams and are much used for food by trappers, prospectors, and natives for themselves and their dogs. Salmon were seen on the Inglutalik as far upstream as camp B9, on the Koyuk above East Fork, on the Kwiniuk above camp C14, and on the Niukluk far above Council. The season of 1909, however, was a particularly poor salmon season, and only a few fish were caught in any of the Norton Bay streams considered in this report.

Salt water forms of life are abundant in Norton Bay and are used for food and clothing. The tomcod, a small, bony fish, and the herring are caught by natives and whites. From the fur of the hair seal much of the clothing of the natives is made, and the skin of the oogruk, a thick-skinned seal, furnishes almost all of the homemade footwear (the mukluk) of the inhabitants. Walrus is sometimes caught near the edge of the ice pack in the spring, and its flesh is used for food.

CLIMATE.

Continuous records of the various elements of climate have not been made in any part of the region for sufficient length of time to afford accurate data for describing the prevailing conditions. The nearest observation stations, at Nome and at St. Michael, are both situated on the coast and give but little information concerning the interior. At present, therefore, there are few records available for the Nulato-Council region except scanty observations extending over only short periods.

TEMPERATURE.

At Nome the highest temperature recorded during 1909 was 70° F., but it is probable that in the interior, where the temperature is not so much affected by the sea, higher records would have been obtained. The work of the Survey party was carried on in the higher hills during the hottest part of the summer, so that the temperatures were much lower than they would have been near sea level. Ice one-quarter of an inch thick formed on water in a pail during the night of July 24 at an elevation of about 1,500 feet at camp B5. On August 5 ice remained on the small pools of water along Peace River at an elevation considerably less than 1,000 feet until after 10 a. m. The hills north of Mosquito Creek and the head of the Fish River valley were heavily covered by snow on September 1, and on September 16 snow covered the ground down to 800 or 900 feet on the southern end of the Darby Range and remained on hills above 1,000 feet for the rest of the season.

The mean annual temperature at Nome for 1907 was 24° F., and for 1908 it was 25° F. As it seems fully as warm at Nome as in the region to the east at the same time, it is probable that the mean annual temperature is not far different for the two localities. The summer temperatures are higher in Nulato-Council region because of the absence of sea control, which would also make the winter temperatures lower, so that these two factors would tend to balance each other. Further data on the temperatures are afforded by a few observations made at Nulato and at the Omilak silver mine, and published by Abbe.[a]

Extreme ranges in temperature (°F.) at Nulato and at Omilak mine, Alaska.

	Jan.	Feb.	Mar.	Apr.	May.	Oct.	Nov.	Dec.
Nulato:								
Maximum	23	29	44	50	71	47	28	31
Minimum	−62	−60	−33	−23	7	−13	−36	−54
Omilak mine:								
Maximum	43	36	43	55	63	36	32	....
Minimum	−33	−52	−36	−24	16	−2	−29	−29

The observations at Nulato from which this table was compiled were carried on for 12 months, from October, 1894, to May, 1895, and from January to April, 1896; those at Omilak mine were also carried on for 12 months, from January 2 to May, 1884, from October 18 to December, 1884, and from January to April 16, 1885. In the report it is noted that in the fall of 1894 the Yukon was closed at Nulato on October 16, and opened in the spring of 1895 on May 22. Near Omilak mine, Fish River opened on May 21, and was closed by ice on September 25, 1884; in 1885 this river opened on May 9.

Dall,[b] who spent a winter at Nulato, has published the following table of temperatures for the different seasons at that place:

Range of temperature at Nulato, Alaska, by seasons.

	°F.
Spring	29.3
Summer	60.0?
Fall	36.0?
Winter	−14.0
Year	27.8

PRECIPITATION.

During the summer of 1909 the precipitation in the western part of Seward Peninsula was abnormally low, and it seems probable that the amount of rain received by the Nulato-Norton Bay region was also less than usual. There were less than a dozen really rainy days from the latter part of June to the end September, but in this period there were 38 days on which it showered.

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[a] Abbe, Cleveland, jr., Prof. Paper U. S. Geol. Survey No. 45, 1906, pp. 133–200.

[b] Dall, W. H., Alaska and its resources, p. 436.

The following table gives the results of previous instrumental observations at Nulato and at the Omilak silver mine.[a]

Mean precipitation, including melted snow and mean number of days with days with 0.01 inch or more precipitation at Nulato and Omilak mine, Alaska.

	Jan.	Feb.	Mar.	Apr.	May.	Oct.	Nov.	Dec.
Nulato:								
Mean total	0.68	0.91	1.46	0.16	0.36	1.36	1.20	1.42
Days	5	7	12.5	2	4	8	6	8
Omilak mine:								
Mean total	0.40	0.32	0.15	0.07	0.02	0.23	0.45	0.18
Days	3	3	3.5	4	2	....	3	3

The record for Nulato was for 10 months, from October, 1894, to May, 1895, and from January 3 to March, 1896; the record for Omilak mine was for 9½ months from February to May and from October 18 to December, 1884, and from January to March, 1885.

From what is known of near-by areas, it may be stated that the amount of precipitation during the 8 winter months is roughly between one-half and one-third of the total for the year. If a factor of this value be applied to the tables so as to correct the total for the year on the basis of the entire 12 months, it follows that the annual precipitation at Nulato is between 15 and 20 inches and from 10 to 12 inches at Omilak mine. This would make the Fish River region about equivalent in moisture to the region near Nome and the region around Nulato much more moist. The region as a whole, however, would be classed as semiarid and similar to a large part of the States of Montana, Idaho, Wyoming, and Colorado. As the larger part of the precipitation comes from June to September, the impression gained by a summer traveler is of a region of much greater rainfall than is actually the case.

WIND.

Throughout the region the northerly winds are the fair weather winds, whereas those from the south usually bring rain. During 1909 the predominant wind direction was from the north, and the weather was accordingly dry for the greater part of the time. Owing to the absence of a heavy cover of vegetation over most of the upland area, the force of the winds is strong and the effects are marked. On the bare limestone hills pieces of detritus are moved by the wind, and the small sand grains are quickly removed from the places where they are formed by disintegration. In many places the foliage on the lower lands is covered with the wind transported dust.

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[a] Abbe, Cleveland, jr., op. cit., pp. 162–165.

Dust whirls caused by convectional currents of air induced by overheating the lower layers were seen several times along river bars. One such whirl started on the Shaktolik River with such explosive violence that it threw up sun-baked pieces of mud several inches in diameter and scooped out a shallow depression. Several dust whirls were noted on the lower part of East Fork and Koyuk rivers and could be traced for several miles across country.

SETTLEMENTS AND POPULATION.

The only villages in the Nulato-Council region are Nulato, Kaltag, Cheenik, Bluff, and Council. Road houses are, however, numerous along the coast and form a complete line from east to west. During the summer there is but little travel, but during the winter the mail and travelers furnish patronage to road houses along the coast at Carson Creek, Walla Walla, Kuiuktulik, Miniatulik, Moses Point, Isaacs Point, Ungalik River, and Shaktolik River. Along Fish River there are road houses between Cheenik and Council, at the mouth of Fox River, and at the mouth of the Niukluk. On the Yukon River are numerous road houses from Kaltag eastward.

A few scattered cabins are the only other habitations in the region, and these are occupied but a short time each year, mainly by trappers. On the lower part of the Inglutalik, 6 or 8 miles from the coast and on this same stream near camp B7, are cabins of this sort.

The mining and prospecting centers of settlements are principally in the vicinity of Bluff and Council on Ophir, Melsing, Mystery, and Goldbottom creeks. There are several cabins, however, on Bonanza Creek occupied by placer miners who hold ground on this stream. At the Omilak silver mine on Omilak Creek, a tributary of Fish River, a mining camp has been established since the early eighties and, although now practically abandoned, at different times has had more than a score of inhabitants. On Bear Creek, a tributary of the Buckland from the west, there has been a small settlement of placer miners since 1902. Two cabins near Alameda Creek, a tributary of Koyuk River from the west, mark a small placer settlement. Ditch camps with one or two men each have been established along the Candle ditch line on Kiwalik River, but are vacant during the winter.

Native encampments are found principally along the coast and belong almost entirely to Eskimos. Along the Yukon are Indian villages, generally established on the outskirts of the white men's villages. The Indians, as a rule, have a more or less permanent abode, but the Eskimos migrate along the coast and are seldom found several seasons in the same place. There is an exception, however, in the case of those owning reindeer. These people usually summer in nearly the same place, but during the fall and winter they are constantly moving their herds from one pasture ground to another. The largest reindeer settlements are near Shaktolik and Cheenik, where the Government herds are located. These herds are mainly tended by natives.

No attempt was made to obtain a count of the population, but, from the best estimates it has been possible to make, it is probable that there are between 1,000 and 1,500 whites and natives in the Nulato-Council region.

DESCRIPTIVE GEOLOGY.

In the Nulato-Council region there are two major geologic provinces, namely, the Cretaceous basin and its inclosing rim. In the mapped area only portions of the western borders of the basin were studied, and neither the northern nor the southern boundaries were determined. In the Cretaceous areas only exploratory surveys were made, and the eastern rim was not visited by the party of 1909. By reason, therefore, of the relatively slight amount of geologic information, this field is shown on the comparatively small scale map, Plate V (in pocket), of the Nulato-Norton Bay region. Farther west, however, the previous work of Mendenhall, Moffit, Collier, Brooks, and Richardson, supplemented by the surveys of 1909, has warranted publication on the larger scale of Plate VI (in pocket), the geologic map of southeastern Seward Peninsula. It should be pointed out that neither map presents the details of the geology, for there are many problems which must await much more searching investigation than the hasty trip of 1909 would permit.

The rocks or deposits of the region may be assigned to six main groups—the undifferentiated metamorphic rocks mainly of pre-Silurian age, the Paleozoic rocks, the Cretaceous sedimentary rocks, the igneous rocks mainly pre-Cretaceous but in part later than that period, the veins, and the unconsolidated deposits mainly of Quaternary age. Each group shows individual characters which are described in the following pages and the areal distribution is indicated on the geologic maps, Plates V and VI. Plate VI is the more serviceable for showing the distribution of the metamorphic and igneous rocks, and Plate V for showing the nonmetamorphic consolidated sediments, but both maps are necessary for a complete idea of the areal extent of the different geologic members.

UNDIFFERENTIATED METAMORPHIC ROCKS.

The greater part of southeastern Seward Peninsula and the southeastern part of the Nulato-Norton Bay region are formed of a series of metamorphic rocks, much folded, sheared, and so changed that in but few places are their original characters preserved. This complex consists of a variety of different rocks grouped on the basis of structure or lithology as schists, limestones, and quartzites.

AREA EAST OF THE YUKON.

The eastern area of metamorphic rocks has not been studied in detail, but the following quotation from Maddren[a] will serve to describe the general lithology:

> The oldest group of sedimentary rocks consists of the quartzite and mica-quartz schists, with associated crystalline limestones, garnet schists, and fine-textured slaty schists or phyllites that form a large part of the Kaiyuh Mountains and extend northeastward across the Yukon to the basin of Tozitna River and possibly southwestward to the Haiditarod. Succeeding this belt of schistose sediments is an extensive group of ancient diabasic effusive rocks that appear to be stratigraphically associated with the schistose rocks. These diabasic rocks have not been deformed nearly so intensely as the schistose group. In places they show greenstone schist phases, but for the most part they have not been greatly altered. Their contact relations to the schists are not known in this region. They appear to flank both the northwest and the southeast sides of the schist belt in the Kaiyuh Mountains, where they extend southwestward to the Innoko, and they have extensive development toward the northeast north of the Yukon as far as Gold Mountain and beyond. No statement as to the thickness of this diabasic group can be made at present.

SOUTHEASTERN SEWARD PENINSULA.

CHARACTER AND DISTRIBUTION OF METAMORPHIC ROCKS.

The schists form the greater part of the metamorphic complex and may be described according to the mineral or minerals characteristic of them. The schists most commonly found are quartzose, graphitic or carbonaceous, biotitic, feldspathic, and calcareous. Gradations between different types are frequent and the differentiation is by no means certain. It appears, however, that the present lithologic differences are in considerable measure due to original characters, so that in a broad way identity of lithology may be taken as indicating deposits formed at essentially the same time. This is generally true of the graphitic schists, is sometimes true of the calcareous schists, and is seldom true of the biotite schists.

Owing to the complexity of structure and the insufficient examinations of parts of the field, it has not been possible to indicate on the map consistently the areas occupied by the various types of schist. It has been found necessary to show areas which, for want of a better name, have been called "undifferentiated metamorphic rocks." These undoubtedly contain representatives of some of the rocks that have been differentiated as well as others, but, as stated above, either the scale of the map or the absence of definite data has precluded accurate mapping. In a measure the lumping together of diverse units has obscured geologic relations, and on the map it frequently happens that the undifferentiated metamorphic rock symbol terminates some other symbol in an abnormal manner. As a specific instance of this kind may be cited the region for 10 miles north and west of Bluff. Detailed traverses along the western margin of this area showed the presence of the feldspathic schists of igneous origin, but no other data are available south of Fox Creek, except in the immediate vicinity of Bluff. Therefore, although it is probable that much of the region is of the feldspathic schist type, it seems unsafe to map the distribution in this 100 or more square miles on such slight evidence. Thus at the risk of obscuring the important fact that the feldspathic schists along the western margin of the map are continuous with the feldspathic schists of the Bluff and Fox Creek regions it has seemed best to adopt the more noncommittal course of showing that the rocks have not been adequately differentiated.

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[a] Maddren, A. G., Innoko gold placer district, Alaska: Bull. U. S. Geol. Survey No. 410, 1910, p. 43.

As shown in Plate VI there are five main areas of undifferentiated metamorphic rocks—(1) around Kwik River, (2) between the two lava flows north of the Koyuk, (3) the Bendeleben Range from the head of Death Valley westward, (4) the western part of the mapped area south of the Niukluk, and (5) along the western flanks of the Darby Range extending southward across the head of Kachauik River to the coast of Norton Bay east of Bluff.

KWIK RIVER AREA.

The schist area at the head of Kwik River shows few exposures in place, and practically nothing was learned regarding the structure and relationship of the rocks of the region except that they are quartzose schists. Toward the east or near the limestone area at the head of Kenwood and Mukluktulik creeks the schists are predominantly very dark and somewhat graphitic, and the rocks may be the equivalent of some of the black slates and quartzites found in places intimately connected with dark limestones. Farther west, however, the similarity to the carbonaceous schists is not so marked, and it is possible that one of the other types of schist is represented.

This schist is highly quartzose in all places, contains some chlorite, practically no garnet or feldspar, and few specimens of it effervesce with acid. Numerous cubical cavities show that it contained pyrite in considerable amounts. It finds topographic expression in a series of massive, slightly dissected hills with gentle slopes covered with waste and devoid of outcrops. Owing to the absence of structural determinations no statement can be made of the thickness or relations of the member. Looked at in detail, however, the minor structures show that the rocks have been so deformed that schistosity has been produced throughout. On the flat-topped, massive hill east of camp C4 the float shows in almost all instances clearly marked evidence of two structures—that is to say, the plication of a previously developed cleavage and color banding. As this structure was not seen in place, however, the relation of the two structures in age could not be determined. The only fact bearing on this point is the occurrence of a shattered anticline west of camp C3, the axis of which strikes northwest-southeast and pitches strongly to the northwest.

AREA NORTH OF THE KOYUK.

The area of undifferentiated metamorphic rocks north of the Koyuk was not visited by the party of 1909. From the manuscript notes of Moffit, who studied the region in 1903, it is evident that a number of different types of schist were found. East of Kiwalik Mountain black slates and carbonaceous schists are closely associated with the limestone area. As the granite contact of Kiwalik Mountain is approached biotite forms an important constituent, although it is of no stratigraphic significance, as it is undoubtedly due to the intrusion of the granite. West of Kiwalik Mountain the schists, according to Mendenhall's field notes, are mainly calcareous, with some greenish schists which may correspond to the feldspathic schists to be described later. Quartz-chlorite schists are abundant in places, but their stratigraphic position, with respect to the others, has not been determined.

BENDELEBEN MOUNTAIN AREA.

According to the geologists who studied contiguous areas in 1900, the metamorphic schists of the Bendeleben Mountains were considered distinct from the other schists of the region and were therefore given a name and assigned to a more or less definite stratigraphic position. In 1908 the senior writer of this report made a cross section of the range along the western margin of the area, and in 1909 the party had the opportunity of studying the section north and west of Death Valley, where rocks previously considered as belonging to the Kigluaik group are exposed. These studies have caused considerable doubt as to the desirability of retaining the stratigraphy as outlined formerly, and these rocks will therefore be treated as "undifferentiated metamorphic rocks."

Mendenhall[a] mapped the Bendeleben Range as two large areas of massive intrusives, mostly granite, with a metamorphic series separating the two. In the text the following statement[a] of this schist area is made:

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[a] Mendenhall, W. C., A reconnaissance in the Norton Bay region, Alaska, in 1900, a special publication of the U. S. Geol. Survey, 1901.

> About the head of Fish River the mountains are chiefly granitic, but along their flanks and sometimes extending through them in belts of varying breadth which mark the passes are areas of schistose sediments.
>
> About a mile above the camp of July 20 along the creek is an outcrop of a rusty and very graphitic schist associated with more calcareous phases. Five miles farther along the right bank of this same branch of Fish River is an outcrop of bluff slates with very little calcareous matter, while 2 miles farther northwest in a gap between two branches of Fish River the series is represented by a white, coarsely crystalline marble. This narrow belt of the crystalline series between two great intrusive granitic masses expands to the northwest.

Collier[b] states in a report published in 1908, the field work for which was completed in 1903:

> The only section across the Bendeleben Range which has been examined by the writer is along Parantulik (Pargon) River and Ella Creek, between the heads of which there is a low pass. The structure here appears to be anticlinal and the prevailing rocks are dark-colored quartz-biotite schists and gneisses similar to those of the Kigluaik Range. Sills and dikes of coarse-grained granite or pegmatite are also present. White crystalline limestones containing scattered grains of graphite occur in beds 20 feet or more in thickness interbedded with the schists along Parantulik River from a point near its head to the edge of the Fish River lowland.

Smith in 1908 studied a section along the upper Niukluk across the range to the northern margin. The examination showed that the section was composed of quartzose schists, a few much dislocated limestones, a complex and very numerous series of granitic intrusives, and black carbonaceous slates and schists. All of the rocks were highly biotitic. North of Birch Creek black slates and calcareous schists predominated. All the rocks were much sheared and original structures were not discoverable, but the diversity of trends of the cleavage noted were such as to lend but slight support to the idea that the structure is in general east and west.

The observations of the party in 1909 in the Bendeleben Range were confined to the extreme eastern part and consisted of a study of the 2,200-foot hill northwest of camp C7, and of the 3,000-foot hill north of camp C8. On the first traverse were found biotitic schists with some thin limestone members and greenstone schists, all thoroughly cut up by granitic intrusions of later date. On the second traverse the same kinds of schists were also found, but in addition there were some carbonaceous schists and greenstones were more abundant.

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[a] Op. cit., pp. 200–201.

[b] Collier, A. J., and others, The gold placers of parts of Seward Peninsula, Alaska: Bull. U. S. Geol. Survey No. 328, 1908, pp. 67–68.

Southwest from camp C8 to C9, 3 or 4 miles from camp C8, the schists are not much intruded by granites and belong almost entirely to the group of feldspathic schists with here and there a few limestones and a little black slate. These schists appear to be fully as metamorphosed as those to the north and strongly suggest a trend more nearly north and south than east and west.

On account, however, of the small amount of investigation in the larger part of the Bendeleben Mountains it seems unsafe to differentiate the schists on the map. They are characterized as a whole by the presence of biotite, but this is of late origin and is not stratigraphically significant. Otherwise all the various kinds of schists and other metamorphic rocks have been recognized, and the series therefore can not be regarded as a unit.

AREA SOUTH OF THE NIUKLUK.

The undifferentiated metamorphic rocks along the western margin of the mapped area south of the Niukluk have been studied in detail where they enter the Solomon and Casadepaga quadrangles. From this study it was determined that the schists were mainly of the quartz chlorite type and that they underlay the limestone near the head of Fox Creek. North of the Niukluk, however, younger schists, called in the region to the west the Puckmummie schist,[a] consisting mainly of black slates and thin limestones, probably overlie the limestone. These rocks seem to merge with the black slates that form the southern flanks of Mount Bendeleben and would indicate enormous deformation not recognizable by surface features.

West of the belt of greenstone schists the rocks show many different lithologic types, but black quartzitic schists, quartz chlorite schists, and calcareous schists predominate in such complex relations that no separation of them has been made. Undoubtedly some of the quartzose schists correspond to the older schists to the west, but some are the sheared equivalents of the heavy limestones and others may belong to the black slate series, which will be described later. In the southern part of this western area a large part of the undifferentiated metamorphic series is the equivalent of the greenstone and feldspathic schist series, but this part has not been closely examined.

AREA WEST OF THE DARBY RANGE.

The fifth large area of undifferentiated metamorphic rocks is along the western flank of the Darby Range and extends southward along the head of Kachauik Creek to the coast west of Rocky Point. In this area schists of a great variety of lithologic types are found in such intricate interrelations that considerable generalization is re-

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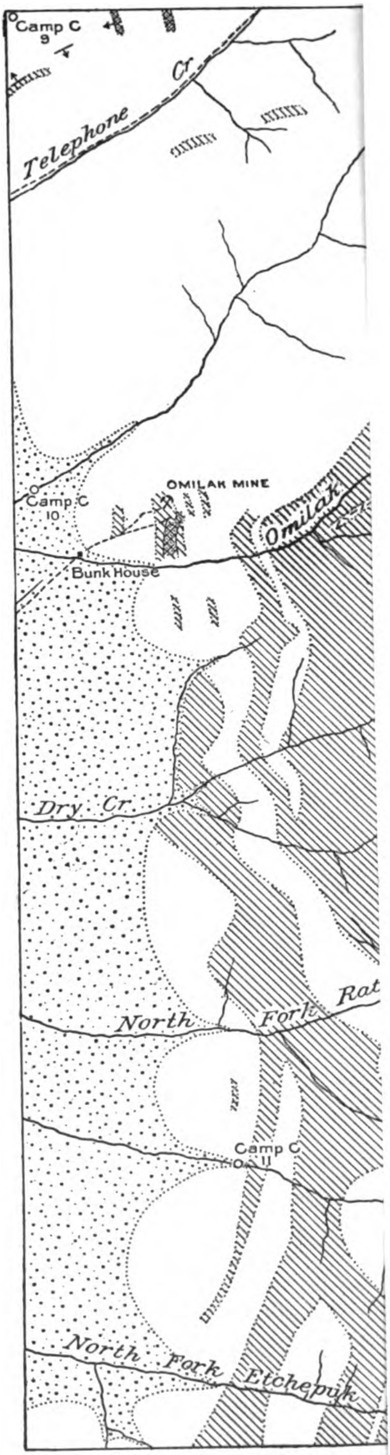
[a] Smith, P. S., Geology and mineral resources of the Solomon and Casadepaga quadrangles: Bull. U. S. Geol. Survey No. 433, 1910, pp. 62-66.


Camp C
9
Telephone Cr.
Camp C
10
OMILAK MINE
Omilak
Bunk House
Dry Cr.
North Fork Rat
Camp C
11
North Fork Etchepuk

quired in mapping them. Plate VII shows a part of this region south of the Omilak mine on a scale of 2 miles to the inch and indicates the geology in some detail. For the present the main interest in this map centers in the arrangement of the various schist and limestone bands. Even on this larger scale map, however, it is impossible to show the actual complexity of the geology. Schists of many different lithologic characters are found in the area covered by this map, but practically all of them are more or less biotitic. Some carbonaceous schists and quartzites suggest the presence of younger members of the schist series, whereas the relations of others show that they are older than the limestones which are believed to be higher in the series.

In the undifferentiated schist area at the head of Kachauik Creek the schists are biotitic, chloritic, and sometimes calcareous, and discrimination of the various types is impossible with the poor exposures. Southward, however, schists lying below the limestone at White Mountain have been recognized by Mendenhall and Collier on Fish River. Similar schists extend southward and probably form most of the hills in the low divide between Norton Sound and the Golofnin Bay drainage. Unfortunately, however, this area has not been studied in detail and the differentiation of the rocks must await further investigation.

SUMMARY.

The undifferentiated metamorphic rocks are highly sheared and cleavage is the dominant structure observed. In many parts of the field the cleavage is at a low angle. In many outcrops where an earlier structure is recognizable the two structures do not coincide, and it is believed that this is the general rule. Faulting is also common in the schists, but the amount of dislocation is generally not determinable on account of the absence of clearly defined horizon markers.

In the typical schist areas where igneous intrusions have not afforded more resistance to erosion, the topographic forms produced are smooth and rolling. Characteristic schist topography is dominant in the eastern part of the Kwik River Basin and is typical of a considerable part of southeastern Seward Peninsula. Here and there on the summits of the ridges rocky knobs of irregular form rise 10 to 30 feet above the surrounding uplands. In the mountainous regions the schists form rugged hills with steep slopes. As a whole, however, the schists are less resistant to erosion than the limestone or igneous rocks and are therefore found in the lower land and passes.

Intrusive activity of several periods has affected the undifferentiated metamorphic rocks. Greenstones, granites, diorites, and other igneous rocks cut these schists and have each had a share in the metamorphism and obliteration of the original characters and distribution of the schists.

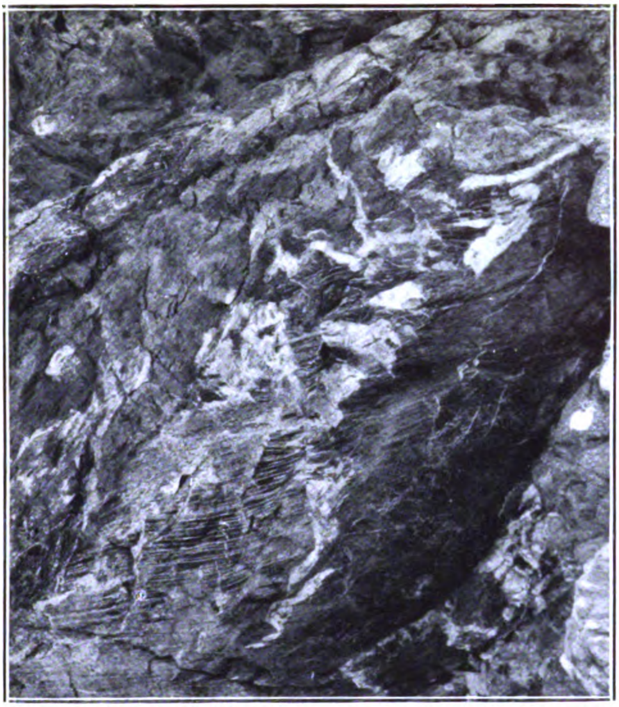
As the undifferentiated schists as mapped include several stratigraphic units of different origin, form, and age, no general statement can be made of the relation of these rocks to the others of the region. It is clear, however, that some of these schists are older than the limestones and other rocks which will be described later, for they underlie them. The question of age and relationship will be discussed more fully in the section on historical geology. For the present, however, it seems justifiable to state that, taken as a whole, the area of undifferentiated metamorphic rocks is composed of rocks older than any of the other areas indicated on the map and is chiefly pre-Silurian.

PALEOZOIC ROCKS.

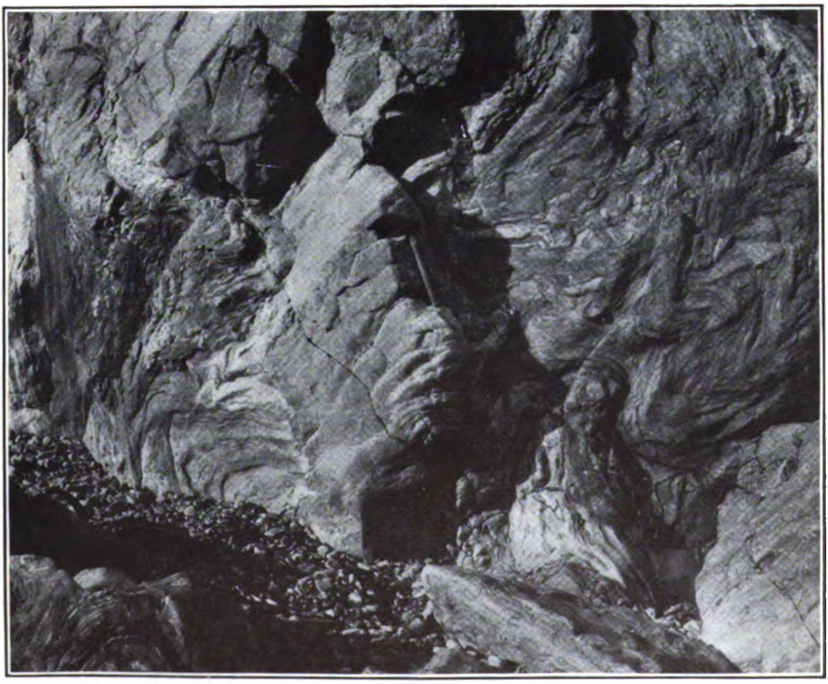
There are five main areas of rocks which are presumably of Paleozoic age, and, although more detailed investigation will undoubtedly show that parts of the undifferentiated metamorphic rocks are of similar age, the lack of information and the complexity of the structure forbid closer correlation at this time. Characteristically all the known Paleozoic rocks are metamorphosed and lithologically consist of limestones and schists complexly folded and faulted. As indicated on the map (Pl. VI), these five areas are as follows: The ridges east of the Darby range extending from the coast of Norton Sound on the south to beyond the Koyuk on the north; the hills east and west of the Fish River gorge from the head of Kachauik Creek to Ophir Creek, including the limestone hills on Fish River near White Mountain; the region south and east of the Omilak mine; the area exposed on the seacoast from Bluff to Topkok Head extending inland an undetermined distance; and the hills at the head of the Mukluktulik. In addition to these larger areas there are smaller areas, some shown on the map and others included in the undifferentiated metamorphic rocks.

AREA EAST OF THE DARBY RANGE.

Along the eastern flank of the Darby Range a group of rocks, consisting mainly of limestones with some schistose bands and closely associated with black slates and quartzites, was noted by Mendenhall in 1900, and studied in some detail by the survey party in 1909. This belt extends from the seacoast with a general northerly trend across Kwiniuk River and along the Tubutulik, forms the eastern divide of Death Valley, and is exposed north of the Koyuk in the hills east of Kiwalik Mountain. Although it probably extends still farther north, its obvious continuation ceases at this place. In this distance the average width of the belt is from 4 to 6 miles. Capital



A.



B.

PALEOZOIC LIMESTONE, DARBY PENINSULA.

A, Intruded by greenstone; *B*, Intruded by granite.

exposures are afforded along the seacoast from the mouth of the Miniatulik southeast nearly to Carson Creek. Studied in detail, the exposures show a great thickness of limestones, considerable dolomite, black carbonaceous slates, and schists, all cut by greenstones, granites, and diorites.

The limestones are in places grayish blue but in other places nearly black. Associated with them in such intimate and complex relations that they can be separated only by refined investigation are dolomites usually of a light-gray, slightly pinkish color. Light-colored dolomites have been recognized in the sea cliff exposures, in the hills between the Kwiniuk and the Miniatulik east of camp C15, and in the hills near camp C5, and east of Death Valley. No measurement of the thickness has been made, but it seems certain that not less than 1,000 feet are required to account for the field distribution.

Although highly metamorphosed, poorly preserved fossils were found in the light-colored dolomite 2½ miles east of camp C15 on Kwiniuk River. According to Kindle, who examined the collection—

> Lot 9AS130, locality 9AS180, Kwiniuk divide, is represented by a single specimen. This is the now well-known though undescribed thick-shelled lamellibranch which has generally been compared with *Megalomus canadensis*. This fossil indicates a late Silurian age for the bed from which it comes. It is interesting to note that it occurs here as at White Mountain (and at the Ramparts of the Yukon) in a highly magnesian limestone. The indexical value of this fossil rests upon our knowledge of its faunal associations in southeast Alaska, where it occurs in association with various late Silurian fossils.

At this place the areal relations are indeterminate. There is some very dark-colored limestone which seems to be either a thin band between two dolomitic bands or else unconformably overlies the dolomite. Northward, however, near camp C5, at the head of Lost Creek, the dolomite lies to the east; that is, apparently on top of the dark limestone. This may be due to intense folding or faulting, or it may be normal depositional sequence.

The limestones associated with the Silurian dolomite range in color from light bluish gray, nearly white, to dark gray, almost black. They are exposed at a number of places in the mapped belt, but the most significant outcrops are those found in the divide between the Kwiniuk and the Tubutulik and along the coast from camp C16 to camp C19. In all places the limestone is folded and contorted with many faults and with calcite and some quartz veins. It has been intruded by greenstones, granites, and diorites. Plate VIII, *A* and *B*, show exposures of these limestones in the neighborhood of the intrusions and afford a fairly good idea of the general characters. Plate VIII, *A*, especially shows the well-marked bedding of the limestone, emphasized by the alternation of bands of light and dark colored limestone. Plate VIII, *B*, shows a more schistose phase, with the bedding marked by the color banding particularly evident in the right-hand portion.

At many places along the sea cliffs poorly preserved fossils were found, and, although none of them was sufficiently perfect or distinct to permit specific determination, there seems to be no question that they represent a higher horizon than that of the dolomite already described. According to Kindle, who examined the collections, a Devonian or Carboniferous horizon is represented, and in his opinion the higher rather than the lower portion is more probable. Ulrich, who examined the fossils hastily, also agreed with the probable Devonian or Carboniferous determination, but appeared to think the lower rather than the higher position was the more probable. There does not seem, however, to have been any marked difference between the amount of metamorphism or deformation undergone by the Silurian and the Devonian-Carboniferous rocks.

In the limestone hills south of the Kwiniuk River conditions similar to those noted on the coast were observed, and it is evident that the same group of rocks is represented. The higher hills are usually formed of limestone, but the saddles are here and there formed of feldspathic schists presumably of later origin. Owing to the scale of the map it has not been practicable to indicate these later schists except in a most general way, but it should be stated that these schists and greenstones are principally of igneous origin; they are not included in this group of sedimentary rocks, but will be described later under the igneous rocks.

In the region between the coast and Kwiniuk River there are, however, slates and schists of sedimentary origin which at the present time are not to be separated from the Paleozoic limestones already described. The precise relation has not been satisfactorily determined and fossils have not been found in them. There is small reason, however, to doubt that they are closely related to the Devonian-Carboniferous group.

These schists and quartzitic slates are perhaps most extensively exposed in the upper part of Mount Kwiniuk, but their structure and other characters are most clearly seen in the coast section. Usually these rocks are of a black color due to the presence of finely divided carbonaceous matter which, in some places at least, is graphite. The rocks are very quartzose and are low in other minerals. Cleavage is commonly developed, but schistosity is not so pronounced as in the older schists. Apparently schistosity is more common in the less quartzose parts of the rock. In the normal quartzose phases the rock has fractured and has had jointing developed, which causes the rock to disintegrate into a talus of small rectangular blocks. No measurements of the thickness of the slate-schist member were obtained, but it must be at least several hundred feet.

From the foregoing description, it is evident that a large mass of Paleozoic sediments which have undergone more or less fully the same general history lies east of the Darby Range. These rocks, which are complexly folded, faulted, and metamorphosed, consist mainly of dark-colored limestones with subordinate thicknesses of dolomite, black slates, and schists. They are cut by intrusives of greenstone, granite, and diorite and in age include members ranging from Silurian to Devonian or Carboniferous, with neither the overlying nor the underlying rocks exposed in close relationship. They have a thickness of at least 2,500 feet and, if considerable reduplication has not occurred, their thickness possibly exceeds this amount many times. They form bold prominent hills with scanty vegetation, covered with an angular frost-riven talus of float, and are widely developed throughout Seward Peninsula.

FISH RIVER AREA WEST OF KACHAUIK CREEK TO OPHIR CREEK.

In the hills east and west of the Fish River gorge from the head of Kachauik Creek to Ophir Creek, including the limestone hills on Fish River near White Mountain, is an area of Paleozoic rocks to be correlated with the rocks of the Kwiniuk region. The most definite data regarding the geology of this field are afforded by the exposures near White Mountain. Fossiliferous beds were found here by Mendenhall in 1900 and have been further studied by Collier, Hess, Kindle, and Smith, but were not visited by the party in 1909. In the description of the exposures on the lower Fish River it will not be possible except at great sacrifice of brevity to credit the particular contributions of each of the different geologists, but it may be remarked that the present writers are acting more in the rôle of compilers than contributors.

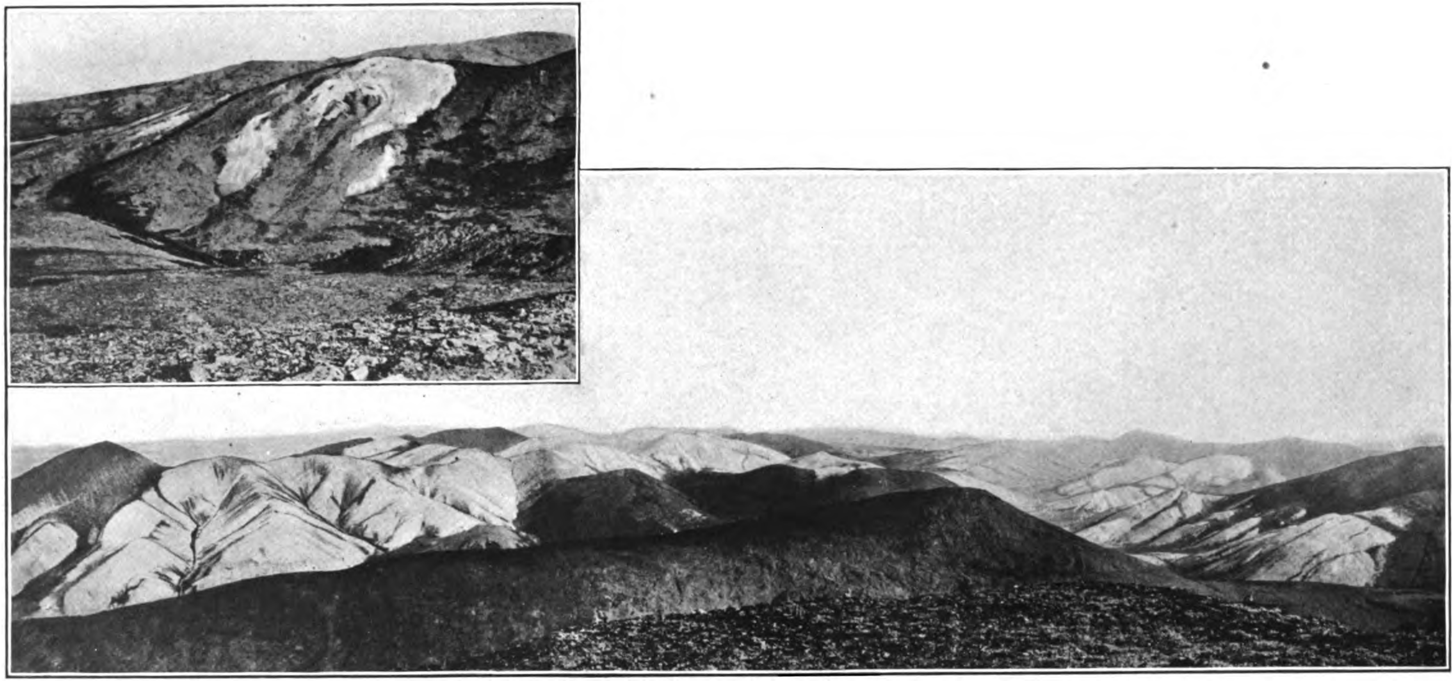
Three miles southeast of White Mountain micaceous, highly metamorphic schists dipping north underlie, probably unconformably, the rocks farther up the river. There is a considerable area of river flood plain in which exposures are lacking, and then come white dolomite hills from which the settlement of White Mountain is named. The dolomite is lithologically identical with the dolomite of the Kwiniuk region, and furthermore contains the same thick-shelled lamellibranch (*Megalomus canadensis*) together with certain other Silurian forms; the correlation seems therefore well founded. Less schistosity has been developed in the dolomite than in the rocks to the southeast, and for that reason there is believed to be an unconformity between the two.

Farther upstream and—if the apparent structure of the rocks is the true structure—overlying the dolomite is a series of schists. Considerable doubt is felt as to the relation of these schists, and it has been deemed expedient in this report to place them among the undifferentiated schists rather than to express their possible correlation with the Paleozoic black slate of the Kwiniuk region, though the latter is by no means impossible. Still farther upstream near the point where Fish River makes an east-west bend south of Steamboat Slough fossil corals have been found in a nearly black limestone. This limestone is lithologically identical with the black limestone of the Kwiniuk locality, and the fossils have been determined to be analogous. As a whole the rocks on lower Fish River are less metamorphosed than in the Kwiniuk region. Near the black Devonian or Carboniferous limestone are black graphitic slates the relation of which is not determinable, but they seem to be lithologically similar to the slates on Mount Kwiniuk in the more eastern locality.

Along the divide between the Fish River lowland and Golofnin Sound from camp C23 west to the head of Mystery Creek limestones with black slates form the country rock. None of the beds, however, were recognized as dolomitic. As a whole the rocks from camp C23 to Fish River are more schistose than their equivalents at White and at Black mountains, but the dominant north-south trend seems to be strong reason for connecting the rocks at the two places. Apparently, the dip of these beds east of Fish River is to the west at rather high angles, but original bedding is seldom recognizable, and the occurrence of diverse dip at places where the two structures have been determined points strongly to the conclusion that the great thickness represented by the surface exposures is due to reduplication through folding.

West of Fish River gorge the schistose character of the limestones is less pronounced, the rock becomes more massive and, although shattered and deformed, shows not much cleavage and but few secondary minerals. Immediately beneath the limestone at the head of Mystery Creek lies a considerable thickness of black quartzitic and graphitic slates. These have not been adequately differentiated in the field, and it is probable that part of the undifferentiated schists on Melsing Creek may belong to the same schist series as those in the Kwiniuk region, for black graphitic slates closely associated with limestones are known to occur at many places in the basin of this stream.

Whether the Paleozoic rocks extend northward across the Fish River flats and are represented by the limestone-slate group at the head of Fish River and Boston Creek has not been definitely proved. It is assumed, however, in the absence of conflicting evidence, that the two areas are the same, and it is on this basis that they have been represented by the same pattern on the geologic map (Pl. VI). According to Mendenhall's field notes the eastern part of this area



WESTERN FLANKS OF DARBY RANGE.

A, Limestone and schist at Omilak mine; *B*, General view from south.

U of M

consists mainly of white crystalline limestone associated with graphitic and rusty schists. So far as his records show, the predominant dip is to the west and the strike northwest.

In 1909 F. F. Henshaw traversed the lower slopes of the hills north of the Fish River lowland from Pargon River as far east as Boston Creek and the geology for that part of the range is represented according to his observations and is only approximate. Whether this belt of limestones may not continue still farther north across the range is not known because of the absence of any field investigation. Although such an interpretation is probable, it has been deemed expedient to truncate abnormally the Paleozoic pattern by representing the northern part of the range as formed of undifferentiated rocks.

In the vicinity of the mountains the Paleozoic rocks are cut by granite dikes and are locally as well as dynamically metamorphosed. South of the Fish River lowland the Paleozoic rocks are also cut by granites and in addition are intruded by greenstones. The latter undoubtedly would be found in the northern area also if more of the region had been examined. It should be noted that where mica-like minerals occur in the Paleozoic rocks near the granitic intrusives the mineral is usually biotite, whereas in the parts remote from the influence of the granite the mineral is chlorite, and biotite is absent.

OMILAK MINE AREA ON WEST SLOPES OF DARBY RANGE.

East of the area of Paleozoic rocks just described there are limestones which resemble in many features those of the Kwiniuk region, and although the correlation is by no means conclusive, it is the closest that can be made with the data now available. No fossils have been found in these rocks and their structure is so complex that any relation between the various units may be postulated. The correlation between the limestones east and south of the Omilak mine has been based almost entirely on lithologic evidence. The geologic map of the Omilak region (Pl. VII, p. 45) shows the distribution of the rocks in greater detail than the general geologic map (Pl. VI). Even this scale, however, fails to express the complex character of structure and areal distribution of the rocks. Plate IX, *B*, shows a view northward from a point on the divide between the two branches of the Rathlatulik about 3 miles east of camp C 11. The white areas in the view are limestones and the darker parts are schist. Some of the schists are undoubtedly derived from rocks of igneous origin, but others were unquestionably deposited as sediments. Most of the limestones are ordinary calcareous rocks, but some are dolomitic. In the view above referred to at several places in the eastern or right-hand belt of white rocks light-colored dolomites have been found. This fact points strongly to the conclusion that these beds represent the dolomitic portion of the Paleozoic rocks of the Kwiniuk region.

With these limestones black graphitic quartzites have been found here and there similar to those on Mount Kwiniuk. This type of rock is not so abundant as at the other places. Its apparently small extent is believed to be due in part to the greater amount of deformation and contact metamorphism whereby it has been transformed into a biotite schist or into a nearly white quartzite.

BLUFF-TOPKOK HEAD AREA.

The westernmost mapped area of rocks correlated with the Paleozoic rocks of the Kwiniuk region occur near Bluff and appear at several points along the western border of the area. Unfortunately, this part of the field has not been thoroughly surveyed, and considerable areas which, if more fully known, might belong to this series have been placed in the undifferentiated metamorphic rocks.

The Bluff region was not visited in 1909 and the account here given is taken from a summary report by Brooks[a] in 1906.

> Richardson, who through his acquaintance with adjacent areas had a broader knowledge of the Bluff region than the writer, divided the bedrock terranes into three groups—(1) a massive gray crystalline limestone, (2) a mica schist with some interbedded graphitic limestone, and (3) a formation of massive limestones and mica schist. The writer's observations hardly bear out the correctness of this succession of beds, for it appears to him that there is only one massive white limestone which is succeeded by a mica schist and graphitic limestone formation. Some facts are presented below which would indicate that the mica schists are, in part at least, altered intrusives and hence do not mark any definite stratigraphic position.
>
> The larger structures of the Bluff region appear to be simple, but there are many minor complications. The heavy limestone has been uplifted into a low dome, whose longer axis stretches approximately N. 70° E. About 3 miles northeast of Bluff this structure carries a limestone underneath the younger mica schists.

It is evident from this description that lithologically the same rocks are represented here as in the Kwiniuk region, namely, limestones, some of which are dark-colored, suggesting the Devonian-Carboniferous limestone and black graphitic slates. The fact that these rocks are cut by intrusives of greenstone is also indicative of a similarity between the two regions. Although Brooks correlated these rocks with the Port Clarence limestone, the fact that Devonian-Carboniferous rocks, as well as Silurian and possibly older ones, may be represented makes it undesirable to continue that correlation, and these rocks are therefore mapped as Paleozoic.

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[a] Collier and others, The gold placers of parts of Seward Peninsula, Alaska: Bull. U. S. Geol. Survey No. 328, 1908—The Bluff region, pp. 285–286.

AREA AT THE HEAD OF THE MUKLUKTULIK.

The fifth and last large area represented on the southeastern Seward Peninsula map as belonging to the Paleozoic rocks is the eastern area in the Mukluktulik divide. This belt trends north and south. On the south it forms Bald Head or Isaacs Point where it is cut off by the sea. To the north a prominent hill locally called Haystack Mountain, on the north side of the Koyuk Valley, marks the farthest extent in that direction; beyond that point more recent igneous rocks have cut or covered the formation.

At the eastern margin of the area is a belt of white quartzite a mile or so in width. This is cut off by basic lavas that form the hills east of Alameda Creek. It is believed that the quartzite is equivalent to the black quartzitic and graphitic slates of Mount Kwiniuk, so metamorphosed locally by the igneous rocks that the carbon has been destroyed. West of the quartzite ridge there is a considerable thickness of calcareous schist with some white limestone bands, but on the divide at the head of Coal Creek a white, completely recrystallized limestone forms knobs trending a little east of north. Sink holes 500 to 600 feet above the sea are common, and some of them show ledges of limestone. This limestone has a strong fetid odor when freshly broken, and shows no original bedding or signs of organic remains. Farther west, about 7 miles from camp B17, at the mouth of the Koyuk, alternations of black graphitic quartzitic slates or schists and limestone beds form an intricate complex about 2½ miles wide trending northeast. The dips, so far as observed, were all to the east, but the arrangement of the different lithologic units is such as to suggest extensive faulting or overturned and crumpled folds.

Northwest of this belt of alternations of black slates and limestones for 4 miles is a series of dark limestones and calcareous schists dipping southeast and striking northeast-southwest. Exposures in this field are rare and unsatisfactory. The western part of this area is formed of a belt 2 miles wide of black carbonaceous slates and schists. No outcrops in place were observed, but the unmixed character of the float points to the conclusion that this is the country rock. It is in all essentials lithologically identical with the slates in the belt farther east already described, and slight hesitation is felt in ascribing it to the same series. More detailed work would undoubtedly permit further differentiation of these two distinct lithologic phases. For the present it may be stated that whereas if, on the one hand, the dip is considered to be dominantly to the east the section shows a black slate and quartzite at the base, succeeded by a thick limestone and limestone-schist member, succeeded by an alternating series of limestones and black slates, succeeded by another thick series of limestones with some schistose phases, and this in turn followed by a massive quartzitic horizon. On the other hand, there are strong reasons for believing that reduplication through faulting and folding may occur, hence there may be only one limestone and one black slate member. No dolomite was observed in this section.

Mendenhall, who saw the section of these rocks near Bald Head, says:[a]

> Along the west side of Bald Head gray and white marbles occur infolded with thin-bedded limestones and schists, and blocks of these rocks cover the beach. The point of the promontory is a mass of heavy black graphitic beds, and the eastern face exhibits a slaty and schistose phase, the rocks being generally dark. Dip and strikes are variable and the relations are obscure, but evidently complex.

SUMMARY.

From the foregoing description it is evident that there is a group of limestones, dolomites, and quartzose graphitic schists which, from the few fossils found, is known to include Silurian and Devonian-Carboniferous horizons. These rocks are on the whole less metamorphosed than certain quartz-chlorite schists on which they are supposed to rest. In general, the trend of the formation is north-south, with complex folding and faulting. No signs of a conglomerate were noted in any part of the section, and it is presumed that the Paleozoic rocks were laid down at some distance from the shore line. This conclusion is further suggested by the wide distribution of lithologically identical rocks over the southeastern part of Seward Peninsula where the metamorphic rocks outcrop. Further investigation might lead to a more precise differentiation of the various lithologic units, but such subdivision would probably not add greatly to the understanding of the economic problems connected with this group of rocks.

CRETACEOUS SEDIMENTARY ROCKS.

In the eastern part of the Nulato-Council region a large area, extending from Norton Bay and Koyuk River on the west to beyond the Yukon on the east, is occupied by a series of sedimentary rocks, including conglomerates, grits, sandstones, shales, and thin lignite beds. These deposits extend north and south beyond the field investigated. The only other rocks within this area are a few dikes near Bonanza Creek, the intrusive massif of Christmas Mountain, and relatively small areas of Tertiary effusives on the Koyuk and near the mouth of the Koyukuk.

Beds similar to certain of those found in the main sedimentary area are exposed at the mouth of Koyuk River and on its north bank at a point about 4 miles west of the mouth of East Fork, also in the long ridge which forms the Kwik-Tubutulik divide. These outlying areas of sedimentary rocks comprise only a few square miles.

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[a] Mendenhall, W. C., A reconnaissance in the Norton Bay region, Alaska, in 1900, a special publication of the U. S. Geol. Survey, 1901, p. 202.

The unmetamorphosed, consolidated sedimentary rocks of the region apparently comprise a single conformable series of great thickness. Two distinct types of deposits are recognized and will be described in their order of occurrence as follows: First, a basal conglomerate called in this report the Ungalik conglomerate; second, an overlying group of sandstones and shales called the Shaktolik group. The Shaktolik group is separated into two divisions, the lower distinguished by a preponderance of sandstones over shale, and the upper in which shales are in excess.

UNGALIK CONGLOMERATE.

The lowest member of the Cretaceous sedimentary series, a basal conglomerate of marine origin, is called the Ungalik conglomerate, after the river of that name, along whose lower course it was first noted. This formation occurs along East Fork of the Koyuk River and on the Kwik-Tubutulik divide. (See Pl. V, in pocket.)

The Ungalik conglomerate is exposed in steep-faced cliffs along Ungalik River and forms most of the prominent range of hills between the river and the coastal plain from Bonanza Creek north to a point about a mile below camp A17. Here the strike changes and the conglomerate appears in the hills east of the river. Its eastern limit was not determined, but its characteristic pinnacled topography does not extend far beyond this point.

In this locality the conglomerate ranges in texture within moderate limits, the coarsest phases carrying bowlders up to 3 feet in diameter. Assortment and bedding are poor. The most characteristic materials are a variety of porphyritic rocks and abundant angular feldspar crystals in the sandy matrix. A strong red coloration on weathering indicates an abundance of iron. The bedding is so indefinite and obscure that no conclusive evidence as to the attitude or thickness of the formation could be obtained. However, a thickness of at least several hundred feet is certain.

That deformation has been intense is indicated by the abundant slickensides developed both in the conglomerate and at its contact with other members. On the Ungalik east of camp A16 it is faulted against black slates which represent a much higher horizon in the series. At this point the slates are approximately vertical. In the bluff on the Ungalik south of camp A16 are several dikes intruded in the conglomerate. They are much faulted and indicate the amount of deformation which has occured throughout the vicinity. The conglomerate area is characterized by a rather rugged topography. Where there is considerable relief the hilltops and sharp ridges are often marked by bare, rugged pinnacles.

The conglomerate is the basal formation of the sedimentary series. It is made up of rounded débris derived from the older formations, on which it rests unconformably. It chronicles a period of more or less gradual advancement of shore conditions.

On East Fork the conglomerate occupies a belt about 8 miles wide, trending north and south. It is similar to that in the Ungalik Valley in texture and in the lack of assortment and bedding. The materials include a variety of igneous rock types in the outcrops near camp B11. Farther west, near camp B12, it consists of a variety of granitic rocks of local derivation. No conclusive evidence as to the attitude or thickness of the conglomerate in the East Fork region was available, but the relief developed in the formation indicates a thickness of at least several hundred feet.

Along the Kwik-Tubutulik divide the Ungalik conglomerate belt has a width of from 3 to 5 miles. The main ridge forming this divide and its northward extension into the Koyuk drainage basin is composed almost entirely of limestone. The bowlders are smaller as a rule than those in the Ungalik and the East Fork localities. There is also greater variation in texture, the deposits including grits and limy sandstone layers. Some of the latter furnished fossil plants of Cretaceous age. Fossil corals taken from a limestone bowlder in the conglomerate on the Kwik-Tubutulik divide about 5 miles south of the camp C4 were of Paleozoic age.

Along the col at the head of Lost Creek the conglomerate is relatively free of limestone and schist material, being made up mainly of igneous rocks and quartz. Vertical dips were observed at a number of places and probably represent the general attitude of the beds in most of this area. The high dips and the fact that the conglomerate area is surrounded by Paleozoic rocks show that the younger beds have been folded or faulted downward from their former relative position, and indicate the extensive removal of Cretaceous sediments from areas which they formerly occupied. As in the other occurrences, the conglomerate marks a period of littoral erosion and deposition, and being derived from the rocks upon which it rests, its relation to them is that of unconformity.

Mendenhall notes[a] the occurrence of unaltered sediments at two points along Tubutlulik River. He says:

> Eleven or twelve miles above the mouth of the Tubutulik some bluish and shaly sandstones and fine quartz conglomerates, entirely unaltered, but dipping 50° or 60° NE., outcrops along the river bank. Two or three miles above this exposure is another of soft, brown sandstone and fine conglmerate with blue clay shales.

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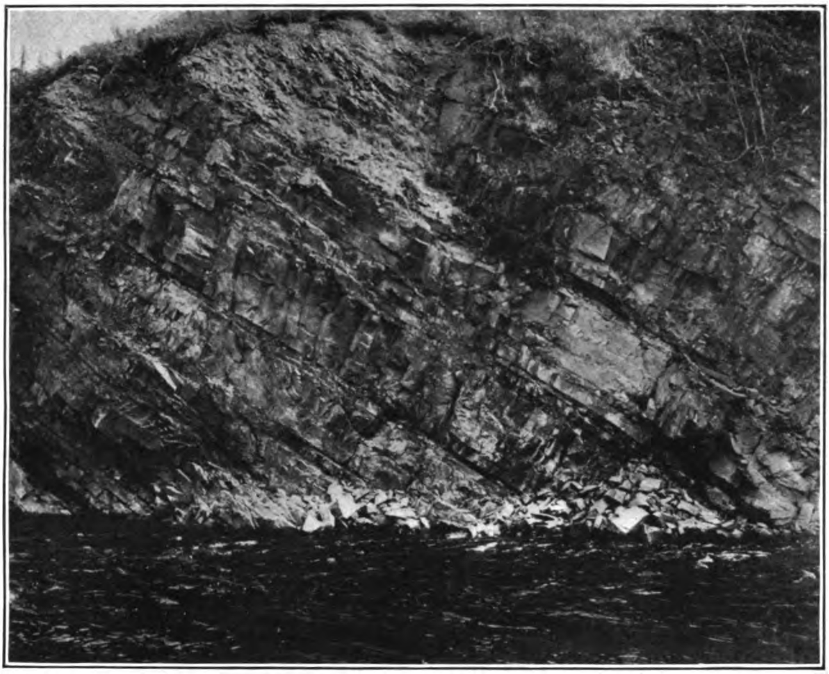
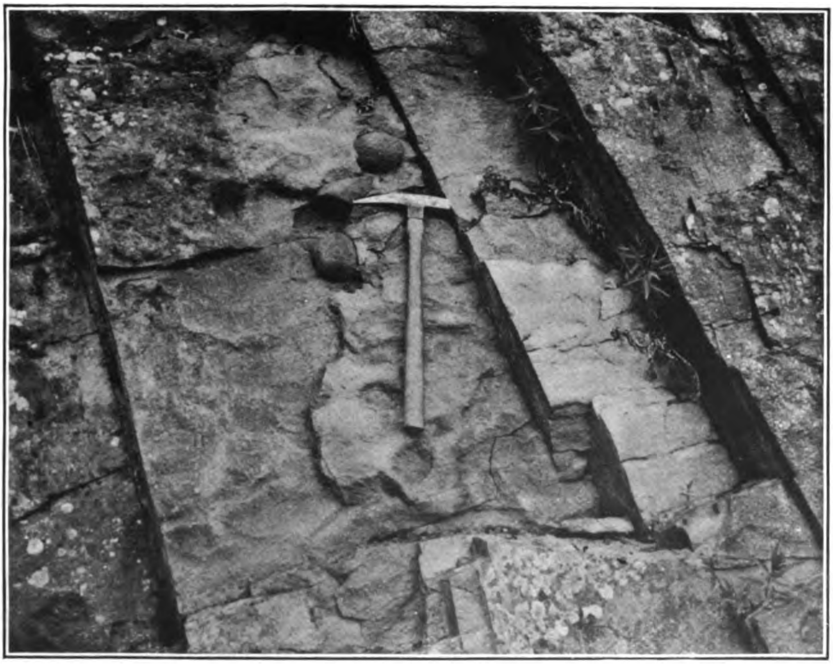
[a] Mendenhall, W. C., Reconnaissance in the Norton Bay region, Alaska, in 1900, a pecial publication of the U. S. Geol. Survey, 1901, p. 205.



A. SANDSTONES AND SHALES OF SHAKTOLIK GROUP, SHAKTOLIK RIVER.



B. CONCRETIONS IN SANDSTONES OF SHAKTOLIK GROUP.

Being immediately adjacent to the conglomerate area and having suffered similar deformation, these sediments probably belong with the conglomerate in the same general series.

About 70 miles east of Nulato, below the mouth of Melozitna River, a series of conglomerates, grits, and shales is exposed along the Yukon. According to Spurr[a] these beds overlie Paleozoic rocks and are made up of materials derived from them. Farther down the Yukon the conglomeratic beds are less important and the series consists mainly of grits, sandstones, and shales.

The determination of fossils collected by Atwood in 1907 from a number of horizons of this series refers them all to the Upper Cretaceous. The Melozitna locality may be regarded as having been at one time the eastern margin of the area of Mesozoic deposition, as the conglomerate areas near Norton Bay indicate the one time western margin.

An exact correlation of the conglomerates of Melozitna River and of the Norton Bay localities is not advocated, though by no means impossible. The similarity of deposits means that the same conditions which prevailed at one time at one of the localities prevailed at some time during the same general period at the others, littoral condition necessarily existing throughout the life of the Mesozoic Basin.

SHAKTOLIK GROUP.

The Shaktolik group, so called after the river of that name, which affords a good section of the beds, includes a thick series of sandstones, shales, and grits. This name is used to designate all the beds between the Ungalik conglomerate and the top of the sedimentary series. Beds of this group are widely distributed in the sedimentary area and occupy most of its space.

For convenience of description a separation into two divisions is made, the lower characterized by abundance of sandstones, the upper by the predominance of shales. Each will be treated separately in the order of stratigraphic position and localities.

LOWER DIVISION OF THE SHAKTOLIK GROUP.

Shaktolik River and westward.—Along Shaktolik River and westward the Shaktolik group is made up of alternating beds of sandstone and shale, the latter aggregating only a small part of the total thickness. (See Pl. X, *A*.) The sandstones are usually fine grained, dense, and compact, and in some places resemble fine-grained igneous rocks so closely in apearance and in constituent minerals that their true character was determinable only with the aid of the microscope. Near camp A10 some of the beds exhibit a peculiar concretionary structure, large spherical masses breaking down in concentric shells under the blows of a light hammer. (See Pl. X, *B*.) Another unusual structure shows in the form of weathered surfaces seen at a number of places in the sandstone area, especially near camps A12 and B6. The surfaces mentioned were marked by linear striations and flutings and by lobate forms suggesting surface flow. (See Pl. XI, *A*.) Whether these structures are original or have been developed by postdepositional movements between beds is not known. Ordinary ripple marks are absent in the same localities.

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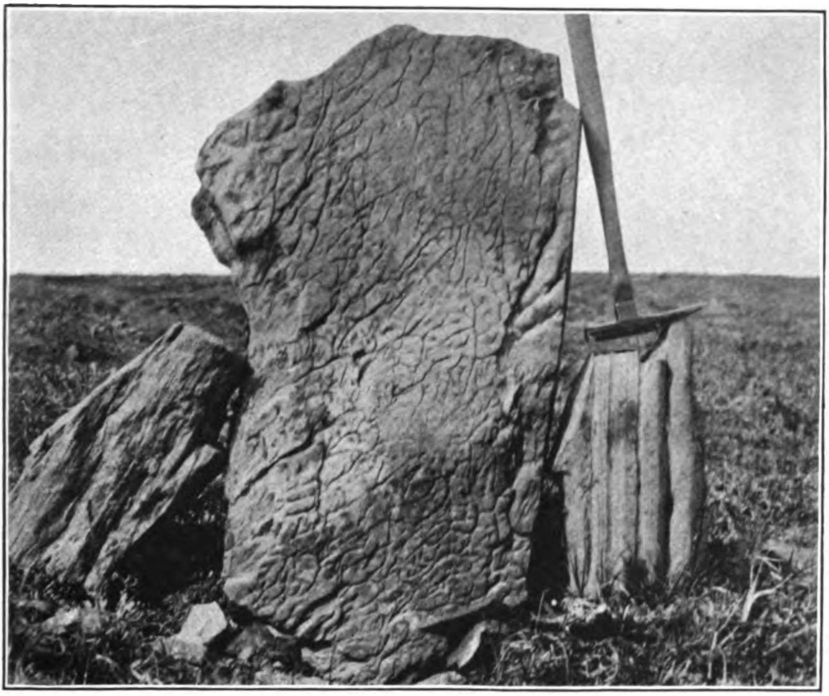
[a] Spurr, J. E., Geology of the Yukon gold district, Alaska: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, p. 189.

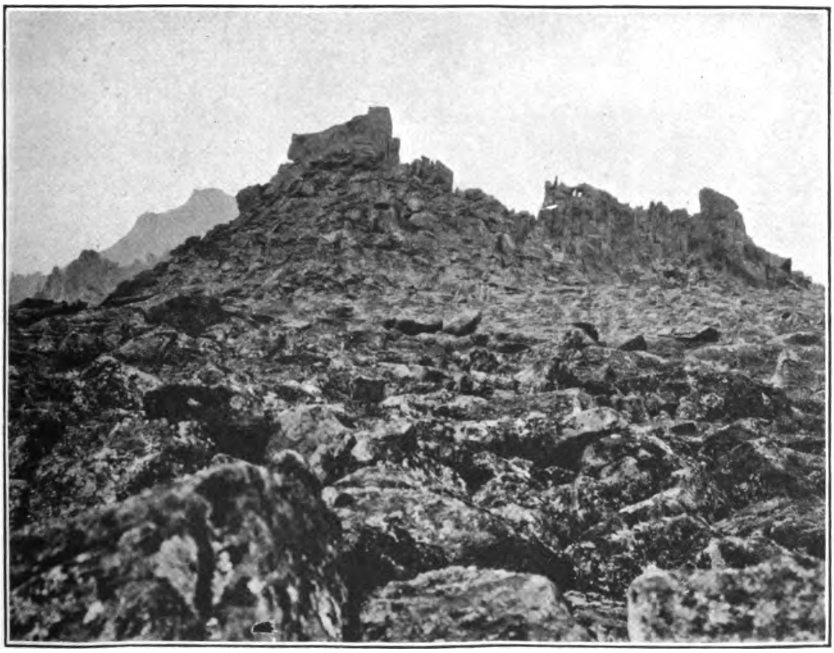
Microscopically, the sandstones show a very even texture. The sand grains are seldom well rounded and are especially sharp in the finer-grained beds. In composition they include feldspars, quartz, calcite, pyroxenes, amphiboles, micas, and fragments of dense igneous rocks. Most of the material of the sandstones could be derived from the rock types that are found in the Ungalik conglomerate. Some of the lower sandstone beds resemble the matrix of the conglomerate closely, pointing to continued sedimentation from the same source. Other beds approach limestone in composition, the sand grains being mainly calcite derived from older limestones. Calcite deposited from solution is the principal cement. Locally, secondary minerals of a serpentinous character, due to the post-depositional alteration of femic minerals, forms the cement, giving the rock a speckled or mottled appearance. Such alteration, however, is not general, the sandstones being remarkable for the unaltered condition of the minerals they contain. The rocks are not highly colored as a rule, shades of gray being most common in fresh specimens. Many of the finer deposits are colored black by carbonaceous matter which they contain. Others have reddish and reddish-brown tones, due to iron oxides. Iron staining is common on weathered surfaces.

The beds have been extensively deformed, close folding along northeasterly and southwesterly axes having occurred. The dips are very high over most of the area, varying within a few degrees on either side of 90° along the Shaktolik. The stronger beds often find topographic expression in prominent ridges, but much of the topography has smooth rounded forms in which both lithology and structure are obscured.

Where good exposures were observed much faulting was noted. In other places, where the structure was obscure in detail, the relation of beds indicated extensive displacement. It is safe to assume that faulting on both a large and a small scale has been an important part of the deformation of the group. Schistosity has been developed locally in places near the structural axes, especially in the fine-grained carbonaceous members.



A. SURFACE MARKINGS ON SANDSTONES OF SHAKTOLIK GROUP, INGLUTALIK DIVIDE.



B. GRANITE PINNACLES NORTH OF KWINIUK RIVER.

The actual thickness of the Shaktolik group at any point is not known. A partial section exposed on the headwaters of the Inglutalik River gives an apparent thickness of tens of thousands of feet. Due allowance for the repetition of beds by faulting being made, the group is still of very great thickness.

The lower or sandy division of the Shaktolik group overlies the Ungalik conglomerate in apparent conformity, and probably grades upward without a break into the upper division of the group, which consists mainly of black shales, and though recognized as distinct in type, could not be differentiated from the lower beds in mapping without more detailed survey.

Near Nulato.—A group of sandstones, shales, and grits with minor lignitic beds outcrops along Yukon River near Nulato. These beds have been known as the Nulato sandstone since first visited by Dall in 1866. They are only a part of a great series of similar deposits which are included in the Shaktolik group. The work in this region has not been sufficiently detailed to determine whether it will be possible to retain the name Nulato for one of the formations of this group.

The early writers, Dall and Spurr,[a] considered these beds of Tertiary age, but subsequent visits of Collier (1902), Hollick (1903), and Atwood (1907) and the study of their collection by Stanton and Knowlton have shown them to be of Upper Cretaceous age. The investigation of 1909 indicates that not only are these beds of Cretaceous age, but that a thickness of several thousands of feet of beds of undoubtedly Cretaceous age overlies them.

In the Nulato section sandstones predominate over the shales, grits, and lignite beds that make up the rest of the group. Notes furnished by Atwood[b] show that different types of beds alternate in close succession. Fossil plants, lignite deposits, cross-bedding, and ripple marks indicate shallow water conditions during part of the period of deposition, but alternating with these are beds bearing marine shells and worm borings. Some of the sandstones are of the even-grained, dense type common in the Shaktolik region and also noted near camp A2. On the whole, the sedimentary rocks near Nulato show a greater variation in type and indicate more changeable conditions of deposition than the rocks of the localities farther west.

The structure near Nulato is rather simple, the beds dipping in general to the northwest at angles up to 40° or 50°. Locally the beds are much faulted and crushed along the axes of minor folds. No definite measurement of the section was attempted, but it must be many thousand feet in thickness. The relations of these beds to the underlying formations are not evident at this locality. They occupy the area west of the Yukon to the locality of camp A5, where they are overlain, probably conformably, by the black shales which form the upper division of the Shaktolik group.

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[a] Dall, W. H., Bull. U. S. Geol. Survey No. 84, 1892, pp. 247–248. Spurr, J. E., Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, p. 196.

[b] Unpublished information; report in preparation.

Bishop Rock.—Bishop Rock is a low, rocky knob on the Yukon about 10 miles above the mouth of the Koyukuk. It is composed of compact limy and shaly sandstones. Fossils collected here by Atwood in 1907 were determined as Upper Cretaceous.

Near Melozitna River.—Overlying the basal conglomerate correlated with the Ungalik conglomerate near the mouth of the Melozitna River and downstream for 30 miles or more a series of sandstones, grits, and shales outcrops along the Yukon. In lithology, fossils, and relation to the basal conglomerates these beds are similar to the Shaktolik group farther west and are regarded as belonging to that group.

UPPER DIVISION OF SHAKTOLIK GROUP.

The upper division of the Shaktolik group occupies the central part of the sedimentary area along the Nulato-Gisasa divide and westward to the head of Shaktolik River. It consists predominantly of black shales, but contains subordinate beds of calcareous sandstone. Some of the latter 5 miles west and 2 miles south of camp A5 furnish invertebrate fossils of Upper Cretaceous age.

This group of beds probably represents a vertical gradation into finer sediments upward in the series, though lateral gradation is not impossible. The shales are very carbonaceous, indurated, and on weathering in places break down into pencil-like fragments. Schistosity has been developed locally near structural axes in some of the more carbonaceous members. The more resistant members stand out in strong ridges; the slopes are steep, covered with fine talus, and almost barren of vegetation. Structurally the shales agree with the underlying standstones, with which they are conformable. Black shales accompany the sandstones throughout the Shaktolik group, but the part of the group in which they predominate strongly enough to be distinguished as a separate division probably does not include more than a few thousand feet.

IGNEOUS ROCKS.

From the foregoing description of the sedimentary rocks it is seen that the Cretaceous deposits give a good horizon to which to refer different geological activities. The pebbles in the conglomerate at the base of the Cretaceous show what rocks were in existence when the beds were deposited, and all igneous rocks cutting the Cretaceous must be later than the beds they cut. For this reason the igneous rocks of the region have been divided into pre-Cretaceous and post-Cretaceous. Each of these main subdivisions contains rocks of different mineralogic composition and field relations and was formed under different conditions; both show intrusive and effusive rocks and afford much material for detailed petrographic studies, which, however, have not been attempted in the preparation of this report.

The larger areas of pre-Cretaceous igneous rocks are the flanks of the Kaiyuh Hills, the Buckland-Kiwalik divide, the Bendeleben and Darby ranges, the region around Bluff, and numerous small areas in the metamorphic complex. The larger areas of post-Cretaceous igneous rocks in the Yukon Valley are at the mouth of the Koyukuk and south of Kaltag; in Seward Peninsula they are in the Koyuk River Basin, especially in the central portion, extending to the head of Kiwalik River; at the very head of the Koyuk, extending to Noxapaga River; and at the lower part of East Fork, extending into the Buckland River basin.

PRE-CRETACEOUS IGNEOUS ROCKS.

In the long time represented by the pre-Cretaceous history of the region there are two distinctly marked periods of much geological significance. One of these preceded the dynamic metamorphism of the region and the other followed it. Rocks formed in the earlier period show structures due to this deformation, whereas those formed afterwards have not been much metamorphosed. A division of the pre-Cretaceous igneous rocks into two groups, metamorphic and nonmetamorphic, may be made, and this grouping will be followed in this report.

METAMORPHIC IGNEOUS ROCKS.

Rocks of igneous origin earlier than the period of metamorphism have been recognized in many parts of the region. The four larger areas mapped are in the Kaiyuh Hills, east of the Darby Range, in the belt extending northward from Bluff in the western part of the area, and north of Omilak Creek. All of these areas have features more or less in common, but it is by no means certain that all of them have been formed at the same time or are mineralogically identical. Furthermore, there is but little doubt that other metamorphic igneous rocks might be recognized if investigations had been carried on in greater detail, and doubtless some of the area mapped as undifferentiated metamorphic rocks is formed of igneous rocks.

Reference has already been made on page 40 to the belts of metamorphic igneous rocks occurring on both flanks of the Kaiyuh Hills. These were described by Maddren as consisting of diabasic rocks of probably effusive character. They are less metamorphosed than the older sedimentary rocks which form the Kaiyuh Hills on which these ancient lavas probably lie unconformably.

In Seward Peninsula the metamorphic igneous rocks are usually greenish in color, and differ much in degree of foliation; in the central part of the peninsula they are high in soda and low in quartz. Usually, where schistose, the rocks have had secondary albite developed and become greenish feldspathic schists. Although the feldspathic character may be produced in other ways, as, for instance, by the contact effect of igneous rocks, it is believed that in a large way the presence in this field of highly feldspathic schists is strongly suggestive of the igneous origin of the rocks in question, and this is assumed to be true if contradictory evidence was not observed.

The clearest evidence concerning the greenstones and associated feldspathic schists is afforded by the cliff exposures along the east coast of the Darby Peninsula. Along this part of the coast are numerous dikes and sills of basic composition cutting the Paleozoic rocks. A particularly clear example of a greenstone intrusion of this sort is shown in Plate VIII, *A* (p. 46). At this place, which is between the Kuiuktulik and Walla Walla, light and dark banded Paleozoic limestones have an unusually low dip. These have been intersected by nearly vertical cleavage, and parallel to this cleavage the greenstones have been intruded. The large white masses shown in the picture are calcite veins of later formation, probably contemporaneous with the succeeding period of mountain building.

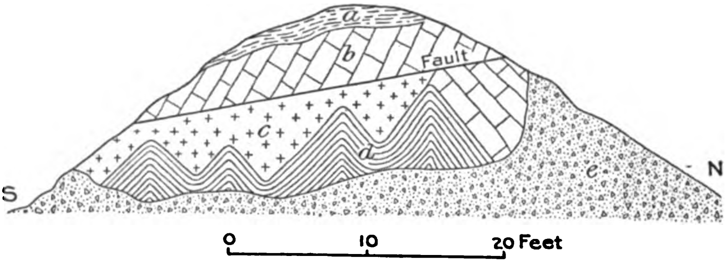

FIGURE 4.—Relation of greenstone, limestone, and slates, east coast Darby Peninsula. *a*, Soil and waste; *b*, limestone; *c*, greenstone; *d*, black slates; *e*, talus.

The structural relations of the greenstones are in places complex and show that these rocks have been subjected to considerable disturbance. Figure 4 illustrates an exposure of slates, limestones, and greenstones on the eastern coast of the Darby Peninsula about midway between the mouth of the Miniatulik and the Kuiuktulik. The greenstone intruded slates and limestones and has subsequently been folded into a number of appressed folds. Thrust faulting then took place along the plane indicated so that the south-dipping limestone was superposed on the greenstone and the slates giving a section as indicated in the figure. The axis of folding at this place is about N. 70° E. and the folds pitch toward the west.

In many places the deformation and accompanying metamorphism of the greenstones has gone so far that the original characters of the rocks are obliterated and it is not certain what origin is to be assigned. Brooks, in a study of the Bluff region, found schistose rocks which seemed to show by their areal relations igneous rather than sedimentary characters. Concerning these schists he says:[a]

> Mica schists occur as irregular masses within the limestone belts and although they do not differ lithologically in any very essential way from the schists believed to be of sedimentary origin, their mode of occurrence strongly suggests that they are altered intrusions. The most striking example of this is seen in the cliff exposures just east of the mouth of Daniels Creek (fig. 5). Here an irregular mass of mica schist is inclosed in limestone walls. Lines of faulting have obscured the original relations of the two rocks, but the outline of the schist mass is very suggestive of an intrusion. Further evidence of the intrusive character of some of these schists is found in the fact that at various localities the limestone walls near the contact with the schists are more or less metamorphosed. These facts, together with the irregular distribution of the schists, indicate an igneous origin, though it must be confessed that the evidence is by no means conclusive.

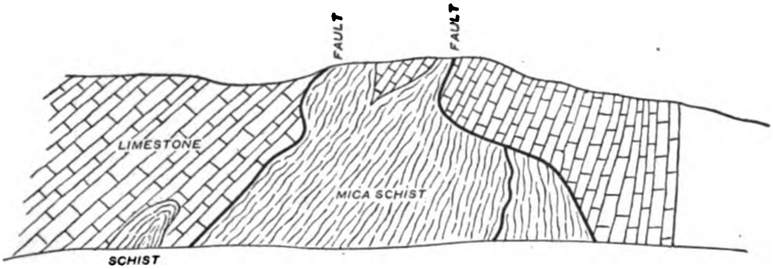

FIGURE 5.—Cliff exposures near mouth of Daniels Creek, Bluff region.

At several places the actual gradation from an unquestionably igneous rock into a green feldspathic schist has been observed. Here and there in the hills south of camp C15 are examples of this sort, and although it is not intended to assert that all the feldspathic schists are of this origin, it is certain that many if not most of them are formed in this way.

An exposure of metamorphosed igneous rock is afforded near the Omilak mine. Figure 6 shows the general geology in the neighborhood of the mine, with the intrusive cutting across the western limb of the limestone. Plate IX, *A* (p. 50), supplements this map by showing the general appearance of the same hill from the south. In this view the dark area in the center of the view is the igneous rock, and an apophysis is represented by the dark band which cuts across the right-hand limestone area. From a study of this rock under the microscope it has been determined that it consists of olivine, a light-colored amphibole probably tremolite, very abundant light-green garnet and muscovite, with some accessory ilmentite and apatite and secondary serpentine. This is an unusual phase of the greenstone series and has not been recognized elsewhere.

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[a] Collier and others, The gold placers of parts of Seward Peninsula, Alaska: Bull. U. S. Geol. Survey No. 328, 1908—The Bluff Region, pp. 285–286.

NONMETAMORPHIC IGNEOUS ROCKS.

There are three large areas of pre-Cretaceous nonmetamorphic igneous rocks to which attention should be called. These are the Darby Range, the Kiwalik-Buckland divide, and the Bendeleben Mountains. In addition, several smaller areas, such as Kiwalik Mountain, are found in the region, but as they show the same features as the igneous rocks in the larger areas they will not be described separately.

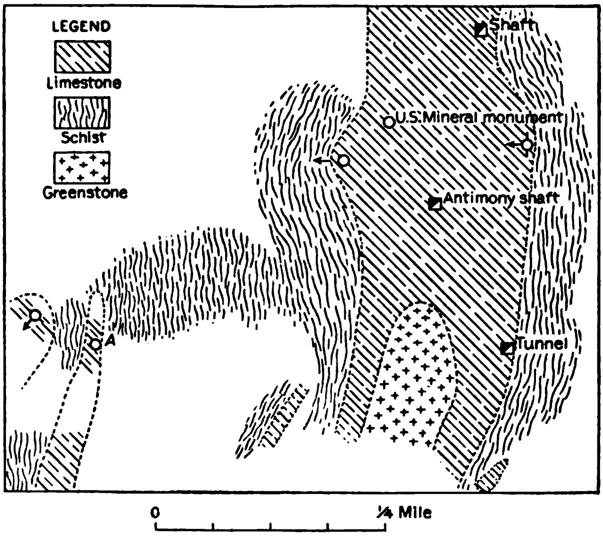

FIGURE 6.—Sketch map of the vicinity of the Omilak mine.

Mendenhall, who studied portions of the Darby Range in some detail, says:[a]

> Cape Darby and a broad belt of country extending 55 miles northward from it with a maximum width of about 12 miles is occupied by a great intrusive body of granite and granitized rock which exhibits considerable variation in texture and mineralogical composition, but is regarded as belonging to one geological body.
>
> A few miles below Cheenik, along the eastern shore of Golofnin Bay, the rock is diorite porphyry with large tabular phenocrysts of andesine or andesine-oligoclase, some colorless pyroxene, and abundant hornblende in part at least secondary. Quartz is present but often in very inconsiderable amounts, and

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[a] Mendenhall, W. C., op. cit., p. 204.

titanite is an inconspicuous accessory. This phase or a slightly more acid one is rather largely represented in this portion of the mass extending at least 5 to 6 miles east from its western border.

Near the eastern edge of the northern part of the area in the Tubutulik Valley the rock appears as a coarsely crystalline aggregate of pale brownish orthoclase and smoky quartz with a little biotite. A gneissoid phase of the same rock occurs along the western side of its western limit.

Distinct contact phenomena in the schists and slates while sometimes present are not so abundant as one would expect. The inference is that the intrusion was slow and deep-seated and affected the intruded rock generally, rather than locally. This inference finds support in the coarse texture and porphyritic character of the diorite even at its borders.

In 1909 it was the intention of the party to avoid revisiting the areas already studied by Mendenhall, so that in but few instances does the work overlap. From this later study it was found that the areal distribution as already given by Mendenhall required but slight modification, but that the number of different kinds of rock was more complex than his report indicated. There are at least two distinct types of granite, one with marked porphyritic development and the other of even grain.

The largest area of the porphyritic granite is in the Kwiniuk basin extending from a little east of camp C14 to at least 4 miles north of camp C15. In addition, the same rock was found on the seacoast at the mouth of Carson Creek and is probably the same as the granite with brownish feldspar described in the northern end of the belt. This rock is characterized by a coarse-grained mass of quartz, orthoclase, and a little biotite, the various grains averaging about 0.2 inch in diameter, with large orthoclase crystals averaging about 1½ inches in length scattered abundantly through the rock. A few inclusions of diorite were found in the porphyritic granite, one of which showed calcite-filled cavities, probably amygdaloidal in origin. Typically the porphyritic granite weathers into fantastic knobs and pinnacles similar to those shown in Plate XI, *B* (p. 58). This feature is also shown more extensively developed in Plate III, *A* (p. 30), the pinnacles shown being probably of granite of this type.

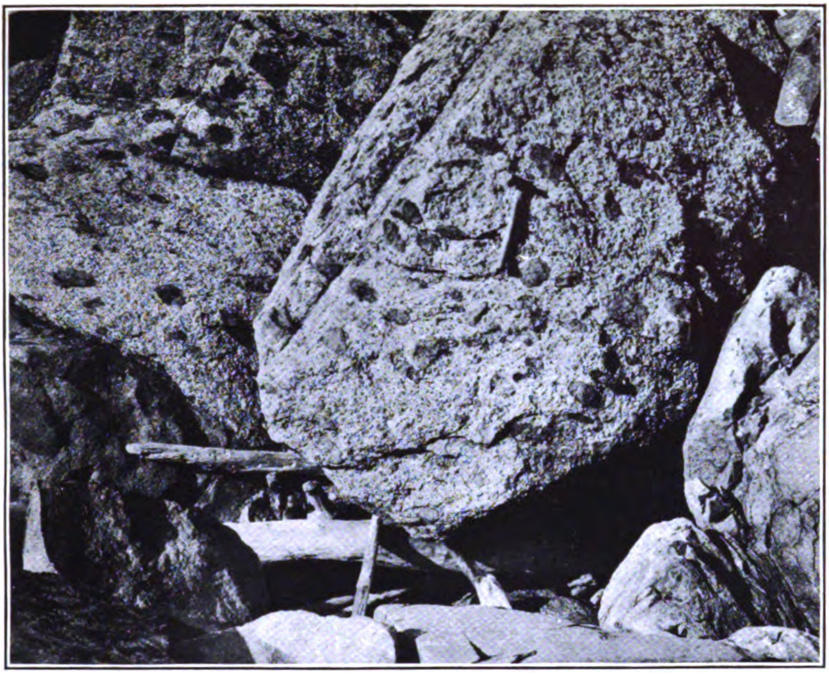
The even-grained granite may be of the same age as the porphyritic granite. If this is the case the two may have consolidated under different conditions. It does not seem evident from the field relations, however, that the porphyritic rock cooled under essentially different conditions except that the porphyritic granite forms larger masses than the finer-grained type. Mineralogically the even-textured granite consists of quartz, both orthoclase and plagioclase feldspar and biotite. Dark-colored silicates, although present, form but a relatively small amount of the rock. It occurs usually in rather narrow dikes, and no large area of this type is known in the Darby Range. Dikes of this granite have already been noted in previous pages as cutting the Paleozoic rocks at many places. Plate VIII, *B* (p. 46), shows a nearly vertical granite dike, the light-colored rock (on which the hammer rests) cutting across the structure of the metamorphic limestone and sending apophyses into it.

Diorite also occupies large areas in the Darby Range. In composition it ranges from a normal amphibole plagioclase rock to one containing quartz and orthoclase in addition to the usual constituents. The plagioclase is apparently andesine-oligoclase; that is, about midway in the soda-lime series. Accessory apatite, titanite, muscovite, and metallic minerals in small amounts were noted in several examples of this rock studied microscopically.

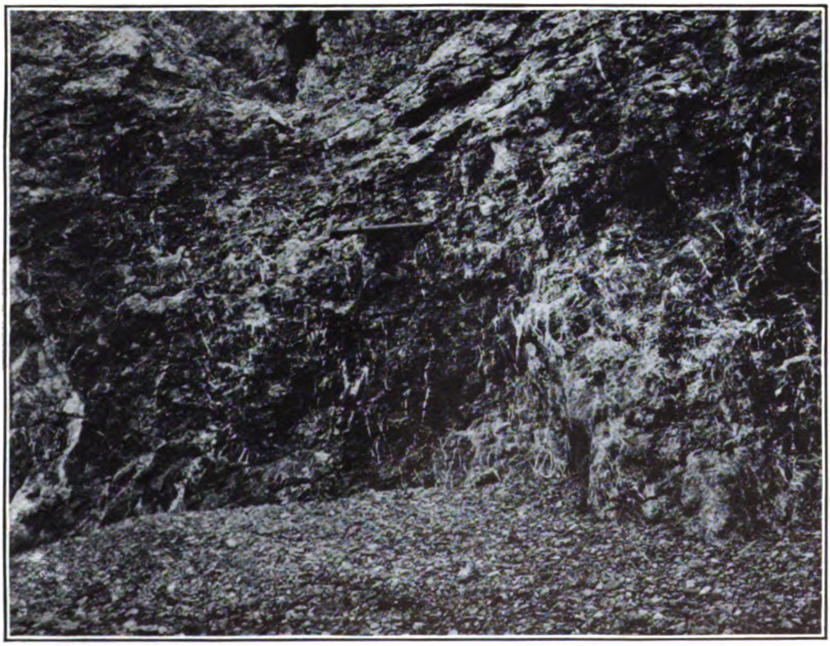
From the fact that inclusions of diorite are found in the porphyritic granite, it is assumed that the latter is younger than some of the diorite. Plate XII, *A*, however, shows that there is more than one diorite represented in the region. In this view the large light-colored area on which the hammer rests is porphyritic granite with numerous inclusions of diorite. Unfortunately in this picture the further fact that the porphyritic granite itself is an inclusion in the dark igneous rock which forms the lower left-hand portion of the view is not shown, although this fact is clearly proved by the exposure in the field. It should further be noted that in this later diorite intrusion are inclusions of the older diorite. Although the similar color makes the two diorites difficult to distinguish in this view, several of the older diorite inclusions may be recognized at the extreme left below the porphyritic granite-diorite contact.

In addition to the granites and diorites there are several other types of rocks, the distribution and relations of which are not sufficiently clear to allow their differentiation. One of these rocks is a quartz porphyry with double terminated quartz crystals and plagioclase as phenocrysts in a ground mass of quartz and orthoclase in a micropegmatitic intergrowth. Accessory green hornblende, apatite, and magnetite with secondary kaolin, muscovite and chlorite were also present. This type of rock was found particularly in the hills south of camp C13 in the divide between the Kwiniuk and the Etchepuk.

Another unusual type of rock forms a large area in the Kwiniuk divide south of camp C13, extending westward an undetermined distance and southward to beyond camp C14. It is dark colored, with lath-shaped phenocrysts an inch or more in length of orthoclase feldspar. The groundmass is composed of orthoclase, albite, oligoclase, green hornblende, ægirine augite, and biotite, with accessory titanite in great abundance, and some apatite. Usually the pyroxene forms cores around which amphibole has been developed, probably by the alteration of the pyroxene. The absence of quartz and the high soda content distinguish this rock from the others already described.



A. INCLUSIONS, EAST COAST OF DARBY PENINSULA.



B. VENATION IN LIMESTONE, EAST COAST OF DARBY PENINSULA.

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Another unusual type of igneous rocks was found on the hill about three-fourths of a mile north of camp C22 on a branch of Kachauik Creek. It is rather closely associated with rocks of the fine-grained granite type, but the precise relations are not known. It is a light-colored fine-grained rock with a few scattered phenocrysts of nepheline and sanidine. In the ground mass, which is very fine-grained, are albite, nepheline, sanidine, ægirine augite, fluorite, eudialyte, riebekite, and biotite. The high soda content suggests correlation with the other soda-rich rock previously described. which was also wanting in quartz.

Rocks similar to the Darby range intrusives, with the exception of the last three phases, have been found in the pebbles of the Cretaceous conglomerate, and no hesitation is felt in ascribing them to an age prior to the Cretaceous. It is also evident from the studies in the field that all of these rocks cut the Paleozoic series and have not been dynamically metamorphosed to any marked extent. That there have been several periods of intrusive activity is shown by the relations of the diorites and porphyritic granites described on page 66. Whether, however, these periods were separated by any considerable time interval or whether they really mark only one major period of intrusive activity has not been determined.

Few new facts of importance have been added to those already published by Moffit concerning the igneous rocks of the Kiwalik-Buckland divide. According to this geologist[a]—

> Much the larger part of the undissected mass which forms the divide between the drainages of the Kiwalik and the Buckland Rivers, and contains the highest elevations of the northeastern part of the peninsula, is made up of light-colored granular rocks and andesites associated especially toward the outer portions of the area with basalts and diabases.
>
> In crossing the main part of the mass from the westward after leaving the highly metamorphic rocks of the Kiwalik Valley one meets first with basic rocks of the basaltic and diabasic type, followed by andesites which are well developed and form a large part of the ridge; finally, in the central portion of the complex, and forming a core for the whole, are discontinuous areas of more siliceous rocks, including a number of different varieties of granites, monzonites, and quartz diorites. Hornblende is the prevailing dark mineral of the granites. but at times biotite takes its place. By a decrease in the amount of quartz the granites approach syenites in composition, such phases being characterized by the abundance and larger size of orthoclase crystals, which usually show Carlsbad twinning and have a rough parallel arrangement with the small intervening spaces filled with hornblende, biotite, and a small amount of quartz. Titanite is abundant.
>
> An unusual and highly interesting type was observed in the most southerly area of the granular rocks. The hand specimens show a dark-gray rock, composed of abundant large tabular feldspar crystals with a small amount of dark-

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[a] Moffit, F. H., The Fairhaven gold placers, Seward Peninsula, Alaska: Bull. U. S. Geol. Survey No. 247, 1905, pp. 27–31.

greenish fine-grained filling. In thin section the rock is seen to consist of large crystals of orthoclase feldspar with a microscopic intergrowth of parallel plagioclase plates embedded in a groundmass of ægirine-augite, melanite, and small scattered plagioclase. The three last-named minerals fill spaces between the large orthoclase crystals, which are very subordinate in volume to the spaces occupied by the crystals themselves. Titanite and apatite are present, and a cloudy zeolitic decomposition product appears at times. The rock corresponds very closely in appearance and composition with the garnet-pyroxene malignites, which Lawson has described, from Maligne River in Ontario.

The diorites present no unusual features. They are nearly always of a light-gray color and are sometimes porphyritic. The prevailing feldspar is plagioclase with zonal structure. Some quartz is always present and the dark mineral is usually hornblende, but at times biotite. In one or two instances a well-developed flow structure was seen in large blocks of the diorite which were cut by small granitic or aplitic dikes largely feldspar.

Monzonites intermediate in composition between granites and quartz diorites are frequent. Orthoclase and plagioclase predominate while hornblende, biotite, and quartz are present; also titanite, magnetite, apatite, and occasionally zircon. All the granular rocks of this region are abundantly supplied with titanite which may often be easily seen in the hand specimen and is very noticeable under the microscope.

Andesites are abundant in the Kiwalik-Buckland divide and are probably the surface representative of an igneous magma corresponding in composition to the deep-seated diorites and monzonites. As already stated, they occupy, where observed by the writer, a position intermediate between the basic rocks of the western side of the ridge and the central acid ones and form a large part of the watershed. They are of a dark-gray or greenish color and on an exposed surface have a spotted appearance due to the alteration of the feldspar phenocrysts. Both hornblende and pyroxene varieties were seen, the latter containing considerable olivine in addition to pyroxene and showing the secondary mineral iddingsite. Alteration of pyroxene to hornblende was also observed. The feldspar is a basic variety, labradorite or sometimes anorthite, giving as alteration products chlorite and epidote.

Andesite breccias were found at various localities.

Little can be added from the work of 1909 to these descriptions and, although it has been possible in a measure to extend the mapping of these rocks, the additional data are so clearly evident on the map that further description is not required, except to note that the extension south of the Koyuk is formed mainly of rocks of the effusive rather than of the intrusive type. It should also be pointed out that whereas the intrusive rocks, which form the core of the Kiwalik-Buckland divide, are in all respects similar to the igneous rocks in the Darby Range, the effusive rocks which occur along the flanks have no recognized representative in the latter mountains.

The igneous rocks of the Bendeleben Mountains so far studied belong mainly to the group of granites, and, although here and there these rocks show gneissic phases, it is believed that, as a group, they are essentially contemporaneous and are later than the post-Paleozoic deformation. Lithologically the granites are indistinguishable from the granites of the Darby or Buckland-Kiwalik ranges, and it is assumed that such close similarity could not have occurred unless all these rocks had been derived from essentially the same magma at nearly the same time. It is on the basis of this assumption that the pre-Cretaceous age of the granite masses in the Bendeleben Mountains is postulated.

In the Bendeleben Mountains the geologic mapping is extremely conventionalized and the reader should regard this part of the map as suggesting the kind of geology probably to be expected rather than as a faithful portrayal of the actual areal distribution of the different types of rock. As mapped, however, this area serves to bring out the fact that there are numerous large bodies of igneous rock, in places many miles in diameter, and also that there is a most complex network of small dikes and sills, many of which are from a few inches to a few feet wide. The lithology and mineralogy of the two types, however, do not materially differ. Some of the small sills and dikes have as coarse texture as the more central parts of the larger masses. Both modes of occurrence are typically quartz-feldspar granites with some dark silicates and various accessory minerals. Even in the gneissic phases, Collier[a] states the structure must either be original or else the whole rock has recrystallized, for the microscopic examination shows little, if any, evidence of distortion or dynamic movement. In other places it is evident that the apparent gneissic structure is due to the replacement of adjacent schists, some of which are so thoroughly saturated by the igneous rock that much of the original character has been destroyed.

The contacts between the granites and the schists, however, are not always vague and ill defined, but in places are sharp and clear-cut. These differences are probably to be explained by the variations in composition of the wall rocks and also by the different depths of burial of the schists when the intrusions took place.

Associated with the normal granites are a few rocks of pegmatitic and aplitic phases which seem to have marked the later or closing stages of the intrusive period. In the pegmatities tourmaline is in places an important accessory mineral. One such pegmatite in particular was noted on Birch Creek near the pass to the head of Niukluk River. Mica in plates sometimes 6 inches or more in diameter is found in the pegmatites. A locality where particularly large mica plates have been reported is near Oregon Creek, a tributary of Fish River heading on the south slopes of the Bendeleben Mountains, and some attempts have been made to develop a commercial deposit.

At a few places dark basic dikes have been reported cutting the granites. Whether these belong to the pre-Cretaceous igneous rocks similar to the latest dioritic intrusion noted in the Darby range or whether they are post-Cretaceous is not known. They form relatively narrow dikes and occupy such small areas in the Bendeleben Mountains and so little is known about them that they will not be treated further in this report.

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[a] Collier, A. J., and others, The gold placers of parts of Seward Peninsula, Alaska: Bull. U. S. Geol. Survey No. 328, 1908, p. 104.

POST-CRETACEOUS IGNEOUS ROCKS.

Later than the deposition of Cretaceous sediments, intrusive and extrusive igneous rocks have been formed. As has already been noted, the main areas of the latter are in the Yukon and Koyuk basins and the only area of the intrusive rocks studied is in the lower part of the Ungalik Valley.

INTRUSIVE ROCKS.

Christmas Mountain, east of the lower part of Ungalik River, is the only center of post-Cretaceous intrusion noted. This prominent landmark is formed of an igneous complex, the relations of the various members being uncertain. The series of rocks grade according to texture from augite andesite to augite diorite. The main mass of the mountain is of the more granular type, in the coarsest phases having crystals up to 3 millimeters in diameter. This coarse phase contains abundant plagioclase, which has been determined to be albite, andesine, and labradorite. Augite, biotite, and olivine are also present as important constituents. Among the accessory minerals are magnetite and apatite, the latter being notably pleochroic. Secondary biotite, chlorite, sericite, and serpentine have also been recognized in this section.

Associated with the diorites in the western part of the area, probably in the form of a dike, is a porphyritic rock composed of orthoclase, plagioclase, biotite, and augite as the essential constituents, and with pyrite and calcite as accessory or secondary minerals. The phenocrysts in this rock are mainly feldspar, but a few are of light-green pyroxene.

The clearest evidence concerning the age of these rocks is afforded by exposures along the Ungalik, near camp A16, where dikes of essentially similar composition are found cutting the Ungalik conglomerate. Subsequent faulting has dislocated the dikes, but the amount of displacement indicated is not more than a few yards. Thin sections of specimens from these dikes show a light-colored porphyritic rock with phenocrysts of oligoclase and a monoclinic amphibole. In the main the ground mass has a trachytic texture and is composed largely of oligoclase and albite, with accessory apatite. Calcite, quartz, magnetite, kaolin, muscovite, and limonite, all probably secondary, were recognized. The limonite is in more or less rectangular patches, which points to its having been derived from the alteration of ferromagnesian minerals originally in this rock. At Bonanza Creek an intrusion of similar character cutting the black slates was found.

On the Shaktolik, at camp A12, a fine-grained quartz porphyry was recognized in the float, but the fragments were well rounded, as though they had been carried far, and there is no clue as to where the rock outcrops. The presence of this float, however, strongly points to the conclusion that it is from an intrusive later than the Cretaceous sediments. It is probable that a more extensive exploration of this region would show intrusive centers like that of Christmas Mountain in other parts of the Nulato-Norton Bay region.

EFFUSIVE ROCKS.

Effusive rocks of late geologic age are found at many places. All of these flows are probably not contemporaneous, but when they are considered in a broad way it is believed that they mark essentially one period of volcanism. Thus, though many years may have elapsed between successive flows, even in the same district, there seems to be strong reason for correlating them together as one group and regarding them all in a geologic sense as synchronous. Although the rocks described in this section are essentially lavas or surface flows, there are, of course, here and there dikes by which these rocks were brought to the surface. All of these rocks are characteristically olivine basalts with a vesicular structure.

The eastern locality of the post-Cretaceous effusives, the one near the mouth of the Koyukuk, was first carefully described by Spurr,[a] from whose account the following quotation is taken:

> Megascopically (the rock) is dark green and amygdaloidal, the amygdules being partly quartz and calcite. Under the microscope a large vesicle whose walls are lined with serpentine is filled with barite in interlocking plates. Many small ovoidal vesicles are lined with serpentine and filled with chlorite. These are comparatively large phenocrysts which are now pseudomorphed by calcite and serpentine, but were probably originally olivine. The structure of the groundmass is as if originally composed of holocrystalline plagioclase and augite. The augite is abundant and not greatly decomposed but the plagioclase crystals have been replaced by pseudomorphs of some other mineral in part, at least, isotropic. The rock is evidently a true olivine basalt considerably altered and decomposed.

Although the lavas represented in the Yukon Valley to the south of this place have not been described in detail they probably belong to the same period of volcanic activity. Similar lavas have been reported by Collier along the river south of Kaltag, but their extent has not been determined and there are no published descriptions of the occurrences. It seems probable, however, from the wide-spread distribution throughout the lower part of the Yukon basin of rocks of this same lithologic character that they must have formed extensive sheets.

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[a] Spurr, J. E., Geology of the Yukon gold district, Alaska: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, pp. 245–246.

Along the eastern border of Norton Bay volcanic rocks of a relatively recent age have been reported at many places. Within the region covered by this report two areas of vesicular lavas have been orally reported to the writers by Mr. J. T. Watkins, of the Coast and Geodetic Survey. These two areas are the Reindeer Hills and Besboro Island. No collections were made, but the description of the rocks clearly points to the conclusion that they are both to be included within this group. They probably mark a connecting link between the well-known volcanic flows of St. Michael on the south and of the Koyuk Valley on the north.

Concerning the lavas along the Koyuk, Mendenhall says:[a]

> The lava is a green, gray, or black rock, the color depending in part upon its freshness. It is compact or vesicular and usually porphyritic, olivine being the most conspicuous of the phenocrysts, although plagioclase is recognizable megascopically in some instances. Sometimes the vesicles are filled with opal; more frequently they are without filling. The rock varies in texture, having sometimes a very glassy groundmass and in other cases showing a coarse, well-defined, interstitial arrangement with almost no glass. * * * The basalt beds have not been disturbed since they were poured out. They are horizontal wherever their attitude is determinable and overlie all the other rocks. * * *

Moffit, who studied portions of the large lava sheet occupying the northwestern corner of the mapped area, as well as numerous other flows in contiguous areas to the north, writes as follows concerning these basalts:[b]

> In color the lavas are dark gray, green, or nearly black. They are usually very cellular or even spongy in appearance, but at times compact and without the amygdaloidal cavities. Outcrops of the older lavas in place are not plentiful, and the edges of the sheets where cut through by streams are marked by tumbled heaps of blocks resulting from the jointed columnar structure of the lava. In a few places they form flat-topped hills or mesas from 20 to 50 feet high, very conspicuous when viewed from a distance, and evidently the remains of partly eroded sheets. Agglomerate breccias were observed at several points. A study of the numerous specimens collected shows them to be made up of diabase and basalts, both rich in olivine. In the basalts, especially, olivine phenocrysts are abundant and very noticeable even in the hand specimens. Iddingsite is not infrequent as an alteration product of the olivine.
>
> That a succession of outbreaks of lava has taken place is shown in a number of places, but probably most plainly in the region about the head of Kuzitrin River, where positive evidence is afforded in the terraced condition of the different flows, three distinct benches occurring in one locality.

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[a] Mendenhall, W. C., op. cit., p. 206.

[b] Moffit, F. H., The Fairhaven gold placers, Seward Peninsula, Alaska: Bull. U. S. Geol. Survey No. 247, 1905, pp. 31, 32–33.

Observations made by Collier on Noxapaga River showed these more recent lavas overlying gravels which are cemented near the contact by indurated clays and contain pebbles of an older flow—conclusive evidence that considerable time must have elapsed between the first outbreak and the solidification of the flows just described. The source from which the recent basalts of Noxapaga and Kuzitrin rivers were discharged lies to the southwest of Lake Imuruk, this being shown by the scattered lava cones as well as by the direction of movement of the flows themselves.

On the upper part of Koyuk River a similar relation of basalts and gravels was observed by Mendenhall. He found on the truncated edges of the schist 5 feet of gravel made up of schist, vein quartz, and granite; this in turn was covered by an undisturbed horizontal sheet of olivine basalt, which has been but little affected by the erosive action of the stream since it came to rest and was, therefore, believed by him to be of Pleistocene age.

During the field season of 1909 little detailed study of the lavas was made, and although the areal distribution of this group of rocks has been extended in certain places the additions are mainly concerning details rather than essentials. It seems evident that in the main they occupy the lowlands of the period in which they were formed, so that a thorough understanding of the distribution of the lavas would indicate the former topography. It is probable that more extensive investigations might show that these basalts occupy a greater area than is shown on the maps. For instance, the lava area at the head of the Mukluktulik probably connected at one time with the lava areas represented to the north of the Koyuk west of Peace River, and if the exposures were better in the gently sloping spurs west of Kenwood Creek it is highly probable that remnants of this sheet might still be found overlying the undifferentiated schists and the Paleozoic rocks. This patch of lava is probably older than those very late effusives that overlie gravel deposits of recent date, but, as before stated, it is believed that they both belong to the same general geologic group and were poured out on the deformed and eroded surface of the Cretaceous and older rocks.

Another small area of recent effusive rocks was reported by Mendenhall in the hills near Grouse Creek, a tributary of the Tubutulik. It covers the contact of the granites and Paleozoic sediments. This fact strongly suggests that the contact, being a zone of weakness, had been topographically a lowland, in consequence of which the lava flowed into the depression and being thickest there had remained, whereas the thinner parts had been entirely eroded away. There is no direct evidence as to the direction from which this lava came, but as no near-by areas of similar rocks are known except to the north it is assumed that this is the direction from which they flowed, although it is realized that this is little more than a working hypothesis.

On Bear River west of Council a small area of recent lava has been reported and specimens of the rock have been examined. It is a vesicular basalt similar in lithologic character to those from the Koyuk. There is probably only a small amount of the rock present, but little is known of the manner of occurrence or the areal relations.

VEINS.

Veins of different mineralogical character formed at different times and under different conditions have been noted at many places. They are abundant in the areas of metamorphic rocks, but are practically absent in the greater part of the area occupied by the Cretaceous sediments. Based on mineralogical composition there are two main types of vein filling; in one quartz predominates, in the other calcite. The former are of widespread distribution and are found in all the various kinds of rocks; the latter class, however, is almost entirely limited to the immediate vicinity of the limestone areas.

The veins in which calcite is the main filling are seldom extensive either horizontally or vertically. They appear to be formed usually as the result of shearing and infiltration of the calcite derived from the adjacent limestones. Plate XII, *B* (p. 66), shows a portion of the Paleozoic limestones on the east coast of Darby peninsula, where an intricate network of calcite veins forms a stockwork through the brecciated limestones. Although the veins are slightly more numerous in this view than in the majority of exposures, the arrangement and general characters are quite typical. Plate VIII, *A* (p. 46), already referred to, shows other calcite veins of the same general mode of occurrence near a greenstone intrusive. Some of these veins are undoubtedly younger than the intrusion of the greenstones, as they cut them or occupy joint planes in them, and it is believed that most of the veins were produced either during or subsequent to the deformation of the Paleozoic rocks.

Calcite is practically the only mineral found in the calcite veins. No sulphides or other metallic minerals have been noted in them, and they are consequently, in this region, of no economic importance.

At least two distinct series of quartz veins have been recognized in the region; in one the veins are much contorted and sheared, in the other crystalline quartz with characteristic comb structure is found. This difference in structure is to be explained by the difference in age of the two types. It seems evident that to have been crushed, sheared, and otherwise deformed the veins must have been in existence at the time of the post-Paleozoic deformation, whereas on the other hand the slightly sheared, relatively undisturbed character of the other group of quartz veins points to the fact that they were formed subsequent to that period. Although these two main groups have been recognized, it is almost certain that the older ones include veins of at least two different ages, one earlier than the Silurian and one later than the Carboniferous, but this point has not been definitely settled and will be difficult to prove owing to the great amount of post-Paleozoic deformation.

So far as can be determined the content of both classes of quartz veins are nearly identical. Sulphide mineralization is usually absent and, although a few copper or iron stains are found at places, the larger part is formed of white quartz seldom even iron stained. Both classes in places carry small quantities of gold. This has been determined mainly by chemical means, for the gold is in the native state and is usually in too small particles to be recognized by the eye. Pieces of quartz from both the older and the younger quartz veins, however, have been seen in which gold was visible. Assays from different auriferous quartz veins have yielded widely varying values, but there is no evident difference between the quantity of gold carried in the two groups. Although the gold content of the older and the younger veins does not seem to be materially different, the fact that the older ones are more shattered and discontinuous renders them on the whole less adaptable to economic development than the younger veins.

Few of the contorted and sheared veins are more than a few inches in width and are usually lens-shaped. Here and there, however, much thicker lenses have been noted, and Mendenhall calls attention[a] to a conspicuous example a few miles north of Cheenik, which is 30 feet by 10 feet by 15 feet. It is described as compact and barren, and exhibiting a brilliant fracture. Other large lenses were seen in the Darby Range and in the Bendeleben Mountains, but they seem to hold no promise of economically valuable minerals. Mendenhall also notes a vein 6 feet wide striking north and south in the sea cliff 4 or 5 miles from Rocky Point, but in this vein the quartz was rusty, as though sulphides were originally present but had been decomposed.

The younger quartz veins are less sheared and shattered than the older veins already described. It should not be concluded, however, from this statement that they have not been subjected to deformation, for they are faulted and discontinuous. Probably like the older veins they may belong to more than one period of formation, but evidence concerning this point is not conclusive. The terms "younger" and "older" quartz veins are therefore to be regarded as purely relative, though in a broad way the former are pre-Paleozoic, whereas the latter are post-Paleozoic. Some of the younger quartz veins cut the pre-Cretaceous granites so that a clue to their age is afforded. No quartz veins have been found in the more recent olivine basalts, and thus the upper limit of their age is determined.

Like the older veins the more recent quartz veins are usually narrow and seldom can be traced for long distances. They are particularly numerous in the black quartzites and slates of the Paleozoic rocks and in that relation form an intricate network of veinlets, many of which are only a fraction of an inch in width. Sulphides, although on the whole relatively unimportant even in the later veins, are more abundant than in the older group. They are usually iron and copper pyrite, but galena, arsenopyrite, and stibnite are found. The latter minerals, however, where found in considerable quantities, as at Omilak and Bluff, are not associated with quartz veins but seem to fill fractures in the country rock.

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[a] Mendenhall, W. C., op. cit., p. 211.

Considering the metamorphic area as a whole, it may be stated that the mineralization is widespread, but that the veins are seldom individually continuous. The mineralization is more in the form of a stockwork or mineralized zone than in sharply defined single veins. Owing to this disseminated character of mineralization the localization of ore bodies is not pronounced, and it is believed that, if commercially valuable deposits are found, they will be more or less similar to the Juneau type of deposits.

Further consideration of the veins which have been prospected will be given in a later part of this report dealing with the economic geology of the region (pp. 127–136).

UNCONSOLIDATED DEPOSITS.

Unconsolidated deposits occur throughout the Nulato-Council region and are important because some of them contain economically valuable minerals. In the following section the distribution and general characters of the different types will be described, the economic features being left for separate treatment in the later chapter on the economic geology of the region. For this reason specific description of the different creek gravels will be omitted here and the main attention will be directed to the more general features of these deposits.

Broadly considered, the unconsolidated deposits may be divided into two classes; in one class the material is practically unsorted, whereas in the other the material has been transported, mainly by water, and deposited at some distance from the place where the waste originated. To the first class belong the talus of frost-riven material and hillside waste covering the surface of most of the upland region; to the second class belong the gravels of various origins and also, for the purposes of this paper, the glacial deposits. There are gradational phases between the two classes, but the main difference on which emphasis is placed is that the latter are in the main water sorted, whereas the former are not.

UNSORTED DEPOSITS.

As has already been stated, the main characteristic of this group of deposits is that they have been little, if at all, affected by running water. Some sorting has, of course, been effected by the gravitative, downhill creep of the material, but this is relatively unimportant. These deposits are, therefore, normally made up of angular material derived from the ledges directly up the slope from the place where they are formed, or they are the frost-shattered fragments of the country rock immediately beneath the surface.

Deposits of this sort are particularly characteristic of the uplands, where the strong temperature changes allow rapid disintegration of the underlying rock. Plate XI, *B* (p. 58), shows a typical view of this sort of deposit in the granite area north of the Kwiniuk, and might be duplicated by pictures from all parts of the field. Of course the waste is not always as coarse as is shown in this view, for the size of the fragments depends upon the physical features of the rocks from which the material was derived. Therefore, in the sandstone shale regions the float is in smaller pieces than in the places where the bedrock is granite.

When the disintegration takes place on a hillside, as shown in the plate (XI, *B*), instead of on top of a hill, the waste as it is formed spreads down the slope and forms a mantle of rock fragments similar to that shown on the hillsides across the valley in Plate III, *A* (p. 22). The foreground of this view shows the general character of this waste sheet on the near side of the valley. Waste sheets of this sort are usually coarser and thinner toward the ridge and become gradually finer and thicker toward the valley floor.

The deposits of unsorted rock waste are so universal that if they were shown on the geologic map they would obscure all the other patterns; hence they have not been represented. This course is further justified by the fact that they have no economic value and are therefore unimportant to the present study. If, then, the reader desires to reproduce the surface features of the Nulato-Council region precisely it would be necessary to imagine practically all of the area not occupied by gravels as covered by the unsorted deposits, except here and there where bedrock outcrops. Such ledges, however, probably do not form one per cent of the entire area.

DEPOSITS OF TRANSPORTED MATERIAL.

The deposits of transported material may be divided into marine deposits, nonmarine water-laid deposits, and glacial deposits. Typical examples of each of these three classes have been recognized in the field, but the gradations between the different classes and the absence of detailed investigations prevent the separation of the three groups on the map. The marine and the nonmarine water-laid deposits show examples of deposits formed at more than one time, so that these two are further divisible into older and younger gravels. The glacial deposits have not been so thoroughly studied as the others and only one division has been recognized. It is by no means improbable that with further investigation these deposits also might be subdivided. It should be noted that the terms "older" and "younger" refer to the relative age within the group and that it by no means follows that one of the older marine deposits is equivalent in time of formation to a particular example of an older deposit of nonmarine water-laid gravels. Such refined correlations must await future investigation. Broadly speaking, however, the group of older marine sediments are equivalent in age to the group of older nonmarine water-laid deposits.

MARINE GRAVELS.

Lithologically the younger marine gravels present great diversity depending in large measure upon the material of which the shore line is composed. The topography also exercises a considerable influence on the physical characters, for in the bights between headlands the materials are fine-grained, whereas near the promontories bowlders and coarse gravels predominate. Near the mouths of the larger streams the mixture of fluviatile and marine deposits is so complex that it is impossible to separate the two. On the present shore line from the mouth of the Koyuk to Cheenik the marine gravels present a great diversity, ranging from fine muds to bowlders 10 feet or more in diameter. Here and there sea stacks interrupt the continuity of the gravels so that the floor on which the present deposition is taking place is irregular. In the sheltered stretches of the coast enormous quantities of drift wood, probably brought down by the Yukon, are accumulating and are being buried as part of the marine deposits. Marine shells, except near the mouth of the larger streams, are not abundant in the deposits being formed at the present time. Garnet and magnetite sand so common along the beach from Topkok westward is almost entirely absent in the eastern part of the coast line.

Marine deposits now somewhat elevated above the position in which they were laid down and consequently belonging to the class of older gravels have been found at many places. These deposits are perhaps best shown by the coastal plain east of Norton Bay north of the Reindeer Hills. Few sections of these gravels have been made, so that their depth and character are not well known. A prospect hole near the mouth of the Ungalik was sunk nearly 100 feet without reaching bed rock. The fact, however, that bed rock outcrops at Island Point only a few miles away shows that the floor on which these sediments have been deposited is uneven.

On the east coast of Darby Peninsula old sea caves 20 to 30 feet above present sea level were recognized at a number of places and are shown in Plates III, *B* (p. 22), and XIII, *B* (p. 66), already described.

Mendenhall also observed evidence of former higher stands of the sea, for he says,[a] "On the west shore of Golofnin Bay raised gravels were observed capping the schistose bluffs at Rocky Point. From this point westward evidence of uplift is increasingly abundant and consists of terraces, high gravels, and superposed streams." From this evidence it follows that at a time not remote geologically the sea stood in places at least 25 feet above its present position, so that considerable areas now dry land were formerly covered by the sea. Therefore marine gravels are to be expected inland from the present shore and have been recognized at many places. Some of these deposits have, however, been subsequently reworked by the streams, so that their marine characters have been obliterated. There is but little question that parts of the gravel deposits at the head of Golofnin Bay and in the bight between the Miniatulik and Isaacs Point are of marine origin, but the transition between the evident marine material and the equally evident fluviatile gravels is so gradual that no line of separation can be drawn without numerous sections not now available.

Not only are there evidences of former higher levels of the sea, but at Bluff a beach line is developed several feet below the present sea level so that at an earlier time the marine gravels did not extend inland so far as they now do. This emphasizes the point that the various members of the unconsolidated marine deposits are not of the same age, but that the sea level has oscillated considerably during a long period.

RIVER GRAVELS.

Every stream in the region is forming gravel deposits and examples of this class are abundantly represented. Owing to the scale of the map, however, only the larger deposits have been shown, so that in reading the map this fact should be constantly borne in mind and it should also be remembered that even in the headwater branches of the smallest streams water-transported gravels are found. As has already been pointed out the creek gravels may be divided into an older and a younger group. These two may so grade into each other that no sharp line of demarcation can be drawn. In this report, however, the lower bench gravels up to 10 or 20 feet above the stream are considered as belonging to the younger group.

The lithologic character of the stream gravels depends very largely on the kind of rocks exposed in the valley in which they occur. Thus in the case of a small stream flowing in a valley carved in only one kind of rock the pebbles are entirely of this kind of rock, whereas in the case of the larger streams, such, for instance, as the Yukon, the gravels have been derived from a great variety of different rocks outcropping within the basin and show a great diversity of lithologic character. So far as has been determined almost all of the younger stream gravels are of local origin; that is, have been formed in the valleys in which they now occur. This point, however, requires considerable additional study, for similarity of rock types and the large area covered are likely to give an appearance of simplicity not justified by more searching examination. An exception to this rule is afforded by the gravels of Melsing Creek, where granite bowlders derived from the Bendeleben Mountains are intimately associated with gravels of distinctly local origin.

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[a] Mendenhall, W. C., op. cit., p. 210.

On the smaller streams the thickness of the gravel is only a few feet, but on the larger streams, especially those that have undergone a complex geologic history, the gravels may be more than 100 feet thick. These deeper gravels undoubtedly belong, in part, to the older ones, but as they grade directly into the present creek gravels differentiation can not be made here, and they will be described at this place. On Mystery Creek, midway between its junction with the Niukluk and the point where it leaves the hills, a shaft penetrated gravels to a depth of 102 feet. The gravels were but slightly waterworn and contained small shells in a perfect state of preservation. Bearing on this same question is the fact that in 1906 a hole was sunk midway between Bear and Fox Creeks west of Council in a bench deposit about 50 feet above the river. This drill hole reached a depth of 250 feet, all this distance being in gravel. Such a depth would make the bottom of the hole at least 50 feet below sea level. As bedrock outcrops within 2 to 3 miles of this place, this thick deposit of gravels strongly suggests the probability of having been formed by an earlier stream which carved its channel when the land stood relatively higher with respect to the sea than it does now.

Another deep gravel deposit has been located in the hills west of the Koyuk near camp B16. At this place a shaft 192 feet deep was sunk all the way through well-rounded gravels. The bottom of the deposit is a considerable distance below sea level and points to a change in respect to sea level since the channel was carved. This channel was probably due to the effusion of some of the post-Cretaceous lavas which obstructed a former stream course, but the fact that the bottom of the channel is far below sea level can be explained only by assuming that since it was formed the region has been relatively depressed. A further description of this deposit is given on pages 110–113.

Although practically nothing is known of the depth of bedrock in the bottom of the Yukon Valley, there are many things which lead to the conclusion that the gravel filling may in places be very thick. This is also true of the Koyukuk and of the lower parts of the

Kateel, the Gisasa, and other large tributaries. It is possible that these deeper gravels are not solely of fluviatile origin, but data are too few to permit a final analysis of the problem.

In addition to the gravels known to belong to an older group, because they underlie the present stream gravels, there are also older gravels whose age is determined by the fact that the stream has cut its valley down into them. In other words, there are bench deposits which mark either a relative uplift of the land or a change in the erosive power of the streams in the recent past. In elevation above the adjacent streams the benches range from only a few feet to several score feet, the higher, of course, being more obliterated by having been exposed to erosin a longer time than the lower.

Russell,[a] who ascended the Yukon in 1890, called attention to certain obscure indications of terraces or sea cliffs at an elevation of 1,500 or 2,000 feet on a number of the hills below Nulato. In traversing these ridges in 1909 the party found no traces of gravel at such high elevations, and it is believed that the appearance of nearly horizontal benches is due to the beveling of the stratified rocks of the Cretaceous, which outcrop in these hills. Lower down, however, at an elevation of about 50 feet above the river, silts and sands form pronounced benches. Although these deposits have not been studied in detail, their position and topographic expression suggest that they mark former river-laid gravels and sands subsequently dissected by the relative down cutting of the present river.

Bench gravels are found in the Shaktolik Valley and were especially noted near camp A10, where a broadly open older valley floor covered with gravels has been dissected by the narrow rock-walled canyon of the present stream. Much of this bench gravel is heavily iron stained. This feature was also noted at several places farther downstream near camp A13. From the topographic similarity it is probable that bench deposits corresponding to those noted on the Shaktolik occur also in the Gisasa and Kateel valleys, but they were not searched for.

In southeastern Seward Peninsula bench gravels are by no means uncommon along the lower slopes of many of the valleys. The deep holes on Alameda Creek and on the Niukluk were started to explore some of these bench deposits and part of the other gravels belonging to this class, but as they grade insensibly into the lower gravels they have been described with the older ones. There are, however, many places, as, for instance, along Ophir Creek, in the Council region, where bench gravels only a few feet thick have been found. Some of these are auriferous and some are not.

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[a] Russell, I. C., Notes on the surface geology of Alaska: Bull. Geol. Soc. America, vol. 1, p. 139.

The geologic significance of the finding of bench deposits at different elevations widely distributed throughout the entire Nulato-Council region is that there have been frequent oscillations of the streams with respect to sea level. These oscillations may have been due in part to climatic changes, but in part they are to be accounted for only by assuming movements of the land with respect to the sea. Although the presence of benches above the streams at the present time shows that there has been an uplift of the land, the fact that some of the larger streams have their rock-cut floors below sea level shows that the sum of the recent upward movements indicated is not at present equal to the sum of the downward movements in the recent past.

A peculiar type of gravel deposit, in part fluviatile in origin, but probably also produced by other agencies, is found in the basin lowlands, such as Death Valley and the Fish River lowland north of the gorge. Sections in these basins have not been made, and little can be determined from the examination of their surficial aspects. Mendenhall states[a] that the Fish River lowland is filled with deposits, "coarse near the borders and fine near the center of the basin. The depth of this filling is purely conjectural, but presumably is not great. No islands of bedrock exist within it, as far as known, but sand and gravel prominences, rising in some instances 30 or 40 feet above the general level, are abundant over it, and are interpreted as remnants of a slightly higher level generally destroyed by the meanderings of the stream." Brooks[b] attributed the origin of these basins to warpings of the crust, whereby depressions were formed, which have been subsequently filled. So long as the topography of the floor on which the gravels rest has not been determined, it seems unsafe to attempt an explanation of their origin. The fact, however, that the uplands are so abruptly cut off by the lowland suggests that the basin is mainly due to erosion rather than to deformation. The question of the origin of the basin is not important in this discussion, for under either view the flats are believed to have been formed by the filling of a depression either by fluviatile or lacustrine deposits.

Owing to the high northern latitude, many of the deposits are permanently frozen, and as the presence or absence of frost in the ground has an important effect upon mining enterprises a general statement of the distribution of the ground ice may be made. Generally the older gravels are permanently frozen and some of the bench deposits contain beds of clear ice in places a score or more feet thick. So far as is known, the presence or absence of trees on the gravels is no sure indication that the ground is thawed, for many instances are known of trees of large size growing on frozen ground. For instance, at Nulato, as Russell[a] states, a well 25 feet deep went through clay and sand beds, which were frozen solid with the exception of certain dry sandy layers, and yet spruce was abundant in the neighborhood before it was cut off. Although most of the older gravel deposits are frozen, those near the present streams are usually thawed. Whether this condition is due to the better drainage of the present stream gravels which prevents the formation of ice is not known. There is a strong suggestion, however, that the frozen condition is due to past climatic controls and is in a way an inheritance rather than a process now in progress. This possibility receives some support from the distribution of ground ice in the marine gravels. In the present beach deposits permanent frost is unknown, whereas in the older ones it is almost universally present.

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[a] Mendenhall, op. cit., p. 207.

[b] Brooks, A. H., The geography and geology of Alaska: Prof. Paper U. S. Geol. Survey No. 45, 1906, p. 282.

GLACIAL DEPOSITS.

Glacial deposits are limited to the mountain regions, and there is strong reason for believing that the Nulato-Council region has not been covered by a large ice sheet in sufficiently recent time to have had any effect on the general topography or on the unconsolidated deposits. Near the Bendeleben and Darby highlands, however, there are indisputable evidences of former valley glaciers of the alpine type. Deposits formed by this agency are of three kinds—in one the materials are unsorted and are dumped in irregular heaps essentially as they were deposited when the ice melted away; in another the glaciers obstructed the normal drainage and thus formed lakes on which ice-rafted bowlders were transported and deposited; in the third the morainic material was transported away from the melting ice by water and so, although originating through glacial action, the present form of the deposits is characteristic of stream deposition.

A particularly clear example of the unsorted morainic material has been reported by Henshaw in the Pargon River valley. At the edge of the mountains where the stream debouches into the Fish River lowland a long spur on the east side of the valley marks the margin of a former glacier. West of this stream, near the same place, the low divide between the Pargon and Ophir Creek is also formed of morainic material, with small kettle holes or depressions irregularly distributed over its surface. Farther up Pargon River a moraine from McKelvie Creek extends out into the main valley and shows characteristic morainic topography. This same condition is also true of Helen, Decatur, and many of the other tributary creeks. The absence of frontal moraines marking the recessional stages of the main glacier is probably to be explained by assuming that the material was washed away by the water from the melting ice and not allowed to accumulate. According to this interpretation, part of the gravels of the Fish River lowland and of Pargon River are of glacio-fluviatile origin. The presence of granite bowlders in the gravels of Melsing Creek is probably due to this period of glacio-fluviatile activity when the ice stood sufficiently far south to allow a discharge from its front across the low divide at the head of Melsing and Ready Bullion creeks.

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[a] Russell, I. C., op. cit., p. 129.

In the upper Niukluk Valley, near Mount Bendeleben, glacial deposits were observed, in 1908, on both the north and the south sides of the range. Moraines are also reported on Baker Creek and Oregon Creek, so that glacial phenomena are observable throughout the Bendeleben Mountains; but the consensus of opinion by all observers is that these glaciers were never very extensive.

Around the higher parts of the Darby Range there are also strong evidences of local glaciation in the past. Marginal moraines, however, have not been recognized beyond the front of the hills and it is probable that they were not deposited. Whether their absence means that they were not allowed to accumulate because of the rapid removal of débris by the water flowing from the front of the glaciers or whether the ice did not extend beyond the front of the mountains has not been determined.

Near camp C13, where the branch of the Etchepuk makes an abrupt angular turn from a southwest to a northwest course, there is abundant evidence of a morainic ridge which is probably responsible in part for the sharp bend in the stream. Although there is no clear proof of the conclusion, it is believed that at one time there may have been a discharge of this branch by way of the Kwiniuk basin. Although the evidence is conflicting, there is a possibility that the Fish River lowland also may be due to glaciation, but this interpretation requires much more detailed investigation and is advanced with many reservations.

That glaciation has considerably modified the topography within parts of the Darby Range by the deposits of glacio-fluviatile material is well shown by the ridges south of camp C11, which form part of the Etchepuk divide. These ridges are mainly due to the work of glaciers that occupied the valleys on either side, but the presence of water-worn cobbles intimately associated with angular ice-transported débris shows that both agencies were operative in the deposition of the material. From the topography it seems probable that this morainic deposit accumulated, as is indicated in fig. 7, where the tongues of ice are represented by CC, with nunataks, or islands of the underlying rocks (AA), separated by low saddles now filled with moraines (BB). The elevation of the top of the morainic material above the floor of the present stream is about 400 feet. East of this point and farther up the ridge there is no evidence of glacial deposits, and bare rock ledges outcrop.

All of these examples of glaciation have been taken from the west side of the range, the one to which the main attention of the party of 1909 was paid. Apparently glaciation is more notable on this side than on the eastern, for Mendenhall says:[a] "Many of the higher areas have not been examined in detail and it is possible that small local glaciers may have existed in the heads of some of the valleys, but no evidence of their existence was gathered during the summer, and views into the mountains from levels but little below their highest points revealed no forms suggestive of ice work."

AGE OF UNCONSOLIDATED DEPOSITS.

A consideration of the unconsolidated deposits as a whole indicates a great diversity of age, represented by the different types. It is not possible as yet to correlate these various deposits definitely, but in a broad way they are more or less closely related; the larger part are Quaternary, but probably none are older than the upper Tertiary. From that as the maximum age they grade down to the present day as the minimum. Assuming that the period of maximum glaciation was practically contemporaneous in the northern hemisphere, the glacial deposits already noted may be regarded as Pleistocene. Certain bench deposits contain mastodon and mammoth bones, which show that they, too, may have been deposited during Pleistocene time. Gravels containing bones of this age have been reported in the Buckland Valley, near Candle, on Ophir Creek, and along the Inglutalik, where they are numerous.

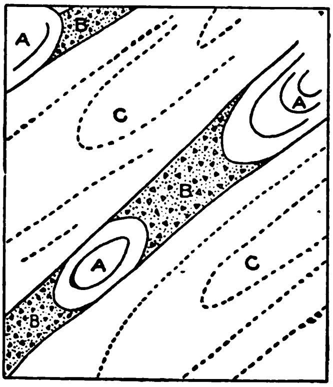

FIGURE 7.—Diagram showing relations of glacial material on Etchepuk divide. (A, Rocky knobs. B, marginal glacial deposits. C, Valley glaciers.)

From the accounts of Henshaw, the well-recognized moraine, at the point where the Pargon River leaves the hills, has been deposited on top of the gravels of the Fish River lowland. Whether this means that all these gravels are older than the glaciation or whether the recognized moraine may only be one of the recessional stands of the ice after a much farther southward advance has not been determined, so that no statement of the age of the two types of gravel can be made. From the meager evidence, however, it seems probable that these gravel-plain deposits are in part contemporaneous with the glacial deposits and in part older than the period when the ice stood at the point where Pargon River leaves the hills.

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[a] Mendenhall, W. C., op. cit., p. 208.

Concerning the age of the marine gravels there is considerable uncertainty. Direct observations in this actual area reveal no evidence, but from analogy with better-known parts of the peninsula there are grounds for regarding them in part, at least, as late Tertiary. The evidence bearing on this point is as follows: In the coastal plain near Nome, which topographically resembles the coastal plain east of Norton Bay, fossils which, according to Dall, are of Tertiary age have been found; furthermore, glacially striated rocks at Nome in the upper part of the deposit indicate that this part was contemporaneous with the period of glaciation. In other words, the lower part of the coastal-plain deposits may be Tertiary and the upper part Pleistocene, and perhaps still more recent gravels rest on top, deposited as the former sea bottom emerged from the water and took on its present relation to sea level. As has been already pointed out, however, a long time is required for the various oscillations of the coast, so that the marine deposits have a considerable range in age.

STRUCTURAL GEOLOGY.

From the foregoing description of the various rocks in the Nulato-Council region it is evident that the structures they present are complex. Already the facts have been brought out that there are a group of metamorphic rocks which were dynamically deformed before the laying down of the Cretaceous sediments, that the Cretaceous rocks have themselves been folded and deformed, and that, latest of all, there have been undeformed lava flows and gravel deposits. It is thus evident that at least two periods of mountain building and deformation have affected the older rocks, and that their present distribution and characters are the resultants of these perhaps opposed actions. These actions have produced enormous dislocation and folding, which can only be vaguely realized and which can not be represented in section except so diagrammatically as to obscure the facts. Furthermore, precise details of complex structure can not be gained on an exploratory survey. It has seemed best, therefore, not to draw cross sections with the appearance of finality, but rather to call attention to the geologic maps (Pls. V and VI, in pocket), from which sections may be constructed. In this way the hypothetical condition will be more clearly discriminated from the actual facts.

The large scale structural features of the region are folds and faults. Many examples of each were observed in the field, and many others must be assumed in order to explain the areal distribution of the various rock groups. In the areas of metamorphic rocks the structure seemed to be simple in places where outcrops were scarce, but was found to be very complex in places where outcrops were frequent or continuous, as, for example, along the seacoast of the Darby peninsula; profound disturbance alone could explain the facts there revealed. In the areas of post-metamorphic rocks, on the other hand, the structures, although deformed, showed larger scale and consequently less complex relations. For this reason the two areas may be treated more or less independently.

The folds and faults produced by the post-Cretaceous deformation are most strongly marked in the Nulato-Norton Bay region. Here the predominant structure trends northeast-southwest and is very pronounced. This structure has had a marked effect upon the distribution of the topographic features, such as ridges and valleys, which are dominantly parallel to this direction. Although the trend of the ridges is undoubtedly due to the structure, the surface in no way corresponds to the surface of the old folded structure; for, although some of the ridges are anticlinal, many are synclinal. Such a condition, of course, would not be produced unless long-continued erosion had dissected the hills. In the part of the divide between the Yukon and the Norton Bay drainage near Traverse Peak the structure is distinctly anticlinal, but the present surface of the hills must be many thousand feet below the former surface. Figure 8 shows in diagrammatic fashion the observations made eastward from near the forks of the Inglutalik, 2 miles below camp B8, to the top of Traverse Peak. The observed dips are indicated by the heavy lines, whereas the implied consequences are shown by dotted lines. In this

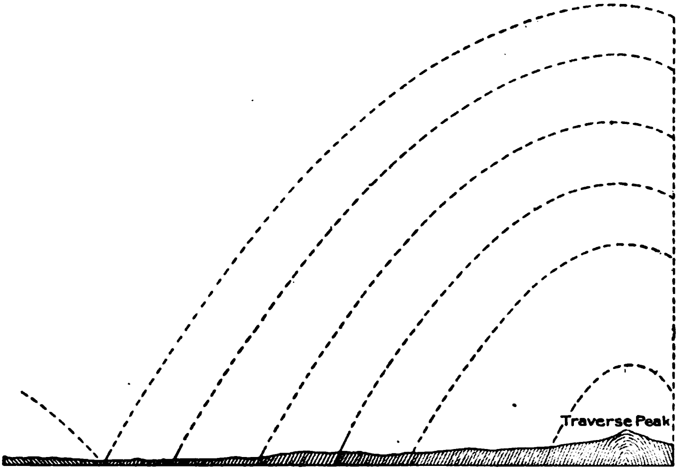


FIGURE 8.—Diagrammatic section west of Traverse Peak.

figure the vertical height of the structure is undoubtedly somewhat too great, for faults of greater or less displacement are to be expected. While, therefore, the diagram is not to be taken too literally, it indicates that an enormous cover has been removed; hence the divide is an erosional rather than a constructional feature. In this connection, it should be pointed out that the thickness of the Shaktolik group, indicated in this diagram, can not be taken as indicating the total thickness of the cover, for the top of the group is not exposed near the forks of the creek in the bowl of the syncline, and there is no evidence as to the distance to the upper surface of the group that has been removed by erosion.

Considered in a broad way the region from the Buckland-Kiwalik divide eastward to the Kaiyuh Hills is synclinal, the folding having a general northeast-southwest trend. It is complicated by numerous folds and faults, so that when examined in detail its larger features become obscured, and in general it shows a rim of the oldest Cretaceous rocks near the margins, with younger rocks toward the center of the synclinorium. In the central part of the area the post-Cretaceous deformation has been expressed mainly by folding, but toward the western part of the region, at least, faults of enormous throw seem to have resulted. This fact is clearly shown by the relation of the Ungalik conglomerate near the Tubutulik. This block, isolated from the rest of the Cretaceous area by a belt of schistose rocks of Paleozoic age or older, appears as a down-faulted remnant of the former extension of the Ungalik conglomerate of the East Fork of Koyuk River. So also the Cretaceous area west of the mouth of the Koyuk seems to be an inset block of sandstone dropped down so far that the conglomerate which should underlie it is not exposed. The absence of the conglomerate at this place shows conclusively that the beds could not have been folded into their present condition, but must have been inset by faulting. No estimate of the displacement represented by this fault was obtained, but it was at least many hundred feet and was possibly several thousand feet.

As suggested in the preceding paragraph, it is believed that many if not most of the larger faults in the area dominantly occupied by the Cretaceous rocks were produced at the same general period as the folding in the central part of the region. Folds passing into faults are well-known phenomena, and it seems reasonable that where the deformation was greatest the beds would be more apt to rupture and produce faults. That the regions outside of the great Cretaceous area were the most uplifted is indicated by the fact that sediments of this age have been removed by erosion more extensively than in the Nulato-Norton Bay region. It is not believed that the absence of Cretaceous rocks over much of the area of metamorphic rocks which form the rim of the present basin is owing to their not having been originally deposited there. The reason for this belief rests on the inset blocks on the Tubutulik and at the Ramparts of the Yukon as well as at many of the less well known localities. It seems that these blocks point conclusively to a former much greater extension of this rock system, which has been gradually decreased as erosion removed the higer parts and exposed the underlying rocks. As to the position of the former shore line of the maximum extent of the Cretaceous sea there is no known evidence, and it is doubtful whether proof can be obtained, as erosion has so extensively removed the traces.

To return to the faults in the Cretaceous area—it has been suggested that many of the larger faults have been the result of the post-Cretaceous deformation, and the reasons for this belief have been stated. Although the validity of this argument may be questioned, as it rests so much on hypothesis, there can be no doubt that certain faults belong to this period. Numerous examples were observed along Shaktolik River where closely appressed folds have been broken and faults have been produced by the deforming forces. It is a notable fact well shown by the excellent exposures along the canyon walls of the Shaktolik that, where the deformation is most intense, as indicated by the close folding, faults are most numerous. Of course, it is only at intervals that the age of these faults with respect to the folding can be determined by direct observation. The intimate relation, however, of faulting to areas of close folding and the observed passage of folds into faults make it almost certain that much of the folding and faulting were contemporaneous.

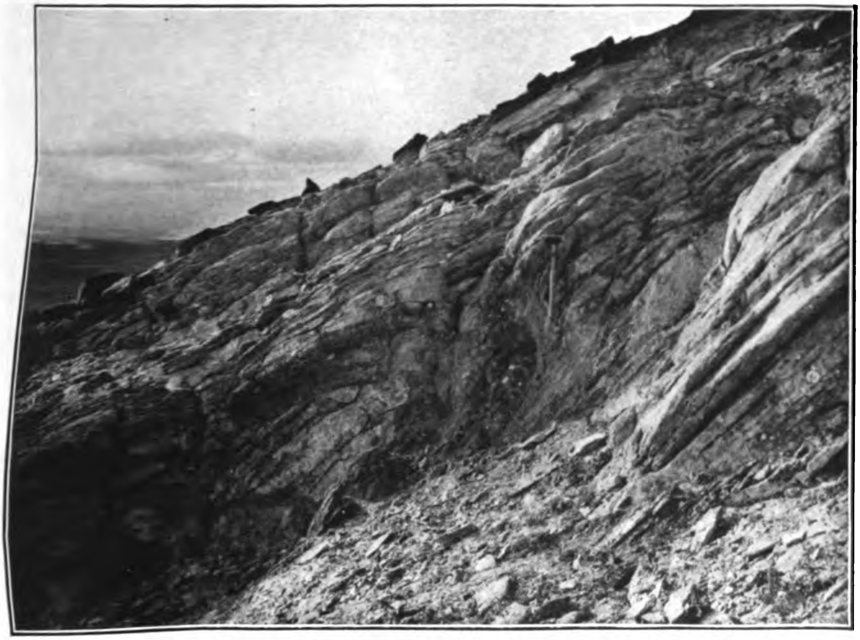
That there has been faulting in the Cretaceous area subsequent to the main period of deformation is clearly shown by the fact that faults have been observed cutting the post-Cretaceous dikes which form apophyses of the Christmas mountain intrusion. Faults of this age were observed near camp A16, on the Ungalik, and there was evidence that larger movements had taken place elsewhere. It is to be borne in mind, however, that the opportunities for obtaining data on the age of the faults are infrequent, and it is by no means improbable that faults later than the post-Cretaceous deformation may be more common and widespread than the single faulted area noted indicates. So far as known, however, it is certain that none of the later faults exercise a direct effect on the present topography.

As has already been pointed out, the period of post-Cretaceous deformation was one of mountain building, and its effects were not confined to the Cretaceous area between the Yukon and the Koyuk, but were extended to the already greatly deformed rocks of Seward Peninsula. Traces of this folding may still be recognized in the dominant north-south trend of many of the structures. An illustration of this trend is seen in the band of Paleozoic rocks along the east side of the Darby Range and also in the various limestone bands west of this range. Although this direction is also the trend of the Darby Range and of the highland of the Buckland-Kiwalik divide, the rocks in both of which are older than the Cretaceous, it seems probable that this form is a post-Cretaceous feature, so that the intrusions were not controlled by this structure. According to this explanation the Darby and the Kiwalik hills are due to the post-Cretaceous deformation, and the fact that the igneous rocks of the two areas are not continuous or aligned gives support to this interpretation. It is not intended, however, to assert that these hills necessarily mark the axes of the deformation, for it is believed that these areas are highlands mainly because the rocks of which they are formed have been strengthened and made resistant by the intrusives which characterize them.

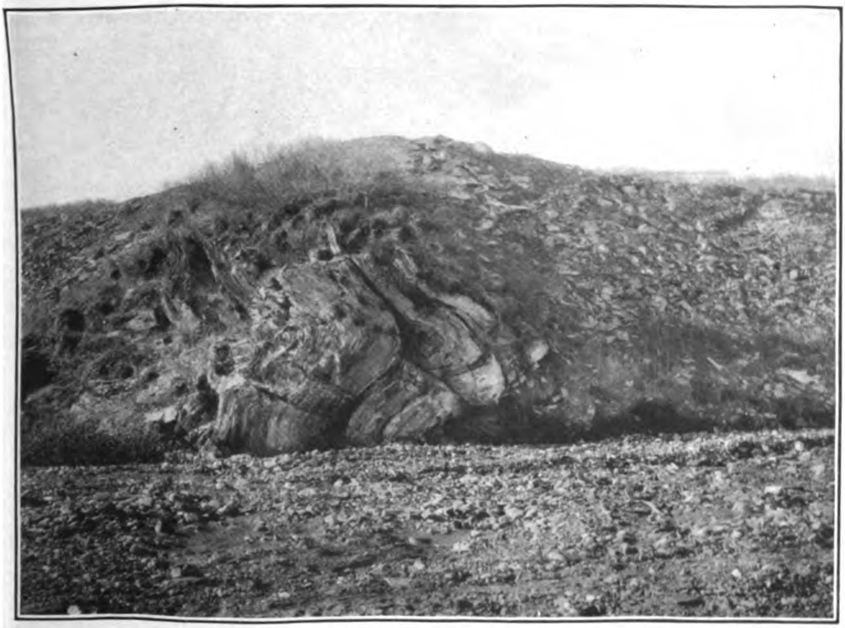
A difficulty in the way of the acceptance of this interpretation is the undeformed character of the granites and other igneous rocks of these areas. Although on the face this is a vital objection, the incontrovertible fact that these rocks form the bowlders in the Ungalik conglomerate makes them certainly older than the post-Cretaceous deformation. Either, then, these rocks were unaffected during this period of mountain building or else they passed through it without marked folding and shearing. That a belt of rocks, averaging in width only about 6 miles and nowhere over 12 or 14 miles wide, should have withstood pressures great enough to fold perhaps 6 miles of Cretaceous sediments into great waves as one would fold the leaves of a magazine is almost inconceivable. It seems far more probable that the deformation that occurred in this part of the field was characterized by faults rather than by folds. According to this explanation great blocks practically undeformed may have been uplifted and oriented in a north-south direction without having been folded or without having had pronounced shearing induced.

With such pronounced post-Cretaceous deformation noted so widely throughout the region, it is evident that the untangling of earlier structures is possible only by the most detailed investigation. Inasmuch as such studies have not yet been made, it follows that interpretations are to be regarded as tentative and as indicating the kind of structures to be expected rather than as stating the precise structure at any particular locality. In order to emphasize the complex character of some of the pre-Cretaceous deformation a few examples of field observation may not be out of place.

Plate XIII, *A*, shows one of the closely appressed folds in the immediate neighborhood of the Omilak mine and very clearly illustrates the point in hand. This illustration is, of course, only one of the smaller folds, for, as is indicated by the hammer, which is about 18 inches long, the outcrop is only about 10 to 12 feet high. It should also be noted in this view that although the folded character of the



A. FOLDED LIMESTONE NEAR OMILAK MINE.



B. FOLDED AND SHATTERED LIMESTONE ON OPHIR CREEK.

beds is very clearly shown in the central and left-hand portion of the picture, the beds on the opposite sides of the axis in the right-hand portion are so nearly parallel that except under favorable conditions of exposure the divergence might be attributed to minor faults or might even pass undetected.

Where the beds are so closely folded it is evident that it is very difficult, if not impossible, to distinguish between the two or more periods of deformation known to have affected the region. For instance, the fold shown in Plate XIII, *A*, has a strong pitch to the west—that is, away from the point of view. Whether this pitch is due to the same deformation which overthrew the fold toward the north (to the right) or whether the overturned fold has itself subsequently been folded parallel to a north-south axis is not known. Figure 9 shows in diagrammatic manner the conditions probably existing at this place, the right-hand part of the diagram representing the part of the area shown in Plate XIII, *A*. As the north-south folds of the post-Cretaceous deformation are the latest mountain building in the region, it follows that the east-west trend noted in the vicinity of the Omilak mine preceded that period and was later deformed by the forces producing the north-south trend. On the other hand, it is entirely within the bounds of reason to suppose that in a period of deformation such as that which followed the laying down of the Cretaceous deposits the dynamic forces would not be equal over the entire area; hence the sag shown in the diagram might occur at a place marking inequality of the deforming force.

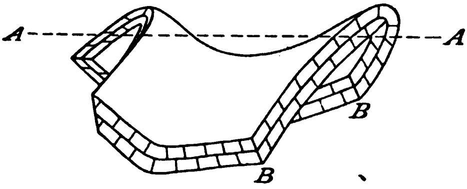


FIGURE 9.—Diagram showing folding in two directions.

Whatever the final determination may be as to the origin of this structure, the fact remains that it is by no means uncommon in the region. The irregular distribution of the different formations seems to suggest a structure of this kind. For instance, if the present erosion surface be indicated by a plane passing through the dotted line AA in figure 9, it is evident that the limestone bed BB would be exposed in the field by two isolated outcrops in which the fold, if it was as closely appressed as the one shown in Plate XIII, *A*, would probably escape detection, owing to the close parallelism of the two limbs.

The reverse of the condition shown in figure 9 might also occur where the field relations would be as though the diagram were looked at upside down and the erosion surface were still represented by the dotted line AA. Under this condition only the synclinal bowls where the rocks had been folded down lowest in the latest period of deformation would be preserved. This condition might, of course, expose either anticlines or synclines of the earlier period of deformation, so that a single observation would afford no conclusive idea of the relations.

With each subsequent folding some of the earlier features are obliterated and structures formed in the previous period of deformation become contorted. Plate XIII, *B*, shows a limestone outcrop about a quarter of a mile above Dutch Creek on Ophir Creek in the Council region that has very evidently been folded so that now the dominant structure is standing vertical. When this exposure is studied in detail it is evident that the thing which has been folded is a previous cleavage and not the bedding. In places, of course, the bedding corresponds to the cleavage, but in this picture it is evident that it is a cleavage that has been folded. This indicates that two periods of folding have taken place; in one the cleavage was produced, and in another it was folded.

Examples of this twofold structure are to be seen in all parts of the field and are not limited to any particular kind of rock, except that two structures are never seen in the later igneous rocks nor in the Cretaceous sediments. Evidences of two structures are particularly notable in the schists and limestones, but the black quartzites of the Paleozoic rocks seem to have fractured rather than folded in the post-Cretaceous period of deformation. Usually in the schists the later folding is recognized by minor transverse plications. The small hand specimens are the miniatures of the larger features, and the reason for the difficulty in recognizing the larger ones is the complexity of the structure and the absence of clearly distinguishable horizons in the schist complex. On the 1,200-foot hill east of camp C4 almost every piece of float gives striking illustration of this double plication.

Of the existence of the two periods described there can be no doubt, for they have been recognized not only in this field but in many other parts of Seward Peninsula. Moffit, who studied the region to the north where the rocks are similar in many respects to those found in the southeastern part of the peninsula, says:[a]

> This complex (the metamorphic group), both sedimentary and igneous in origin, was affected by the two movements mentioned, which acted in very different directions. One produced a structure in which the axes of the folds extend in an east-west direction, and is most plainly expressed in the uplift constituting the Kigluiak and Bendeleben mountains. * * * This east-west structure corresponds in the direction of its folds with the main structural lines of the whole of western Alaska, and is believed to have been produced before the deposition of the coal beds; that is, before Cretaceous or lower Tertiary time.
>
> The second movement resulted in the production of folds whose axes have a general north-south direction and are the dominant structural feature of the northern portion of the peninsula.

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[a] Moffit, F. H., The Fairhaven gold placers, Seward Peninsula, Alaska: Bull. U. S. eol. Survey No. 247, 1905, p. 35.

It has already been suggested that the schists which underlie the Paleozoic rocks were probably deformed prior to the deposition of that member of the stratigraphic sequence and that the later rocks lie unconformably upon them. This is a difficult thing to prove and is advanced tentatively. There is no place where the underlying and the overlying rocks occur so intimately associated that the possibility of faulting is precluded, and, although the underlying rocks are much more schistose and apparently more deformed, there is necessarily the uncertainty as to the weight that should be given to this evidence when applied to lithologically different rocks. In spite of these objections it is believed that there was a period of profound pre-Silurian deformation. Definite proofs of this event have been, in the main, removed by the two subsequent periods of mountain building, but the constant greater metamorphism of the supposedly older schists, the field relations of the two groups, and the presence of certain structures in the older schists not found in the Paleozoic rocks lead to the conclusion that there was a period of pre-Silurian deformation.

If this hypothesis proves to be correct, it follows that an exceedingly complex arrangement of the lithologic members of the older schists is to be expected, and that the final determination of the succession in that group will be accomplished with the utmost difficulty. For the purposes of this paper, however, it will be sufficient to point out that the effect of each period of deformation has been to make the distribution of the older rocks more and more irregular, and, if the term may be applied to distribution, smaller "textured." As to the trend of the deformation of the oldest folding, there are no data available on which to base even an approximation.

HISTORICAL GEOLOGY.

To one who has followed the preceding descriptions with geologic insight the successive events which occurred in the region have already been given. As the facts for making a relative chronology, however, have been scattered through many pages, it seems desirable to collect these details into sequential order which shall give an epitome of the geologic history of the Nulato-Council region.

The oldest recorded event from which a start can be made was the laying down of quartzose and calcareous sediments over much of what is now western Alaska under presumably marine conditions. No definite age for this event can be given. It was, however, undoubtedly earlier than the Silurian. From the evidence secured by Kindle in the York region of western Seward Peninsula, where the Ordovician and Upper Cambrian seem to form a continuous relatively uninterrupted sequence overlying similar rocks, there is some warrant for considering the oldest rocks as possibly pre-Cambrian. This suggestion as to the age is to be regarded only as a working hypothesis and is by no means definitely proved.

After the deposition of these sediments there were probably some veins formed which are now represented by the knotted and contorted quartz strings found in the older schists. Either coincident with this venation or following it, probably the latter, a period of mountain building ensued in which the quartzose and calcareous sediments previously deposited were consolidated and deformed and cleavage was probably developed. Erosion followed and sediments from this old land were carried out and deposited in the sea. This process must have continued for such a long time that the highlands were reduced by erosion and the region subsequently became depressed below the marine waters, for the rocks formed of the waste thus washed from the land were apparently deposited unconformably on the underlying rocks. If the tentative assumption of the pre-Cambrian age of the oldest sediments is correct, this period of mountain building may mark the gap between the Paleozoic and the pre-Paleozoic. In this period undoubtedly many oscillations and minor deformations may have occurred which are now unrecognizable.

After the period of mountain building the material eroded from the land mass was deposited in the marine waters off the coast. The land from which this waste was derived was remote from the area under consideration, for the sediment derived from it that now covers part of Seward Peninsula was laid down as limestone. In the Nulato-Council region this deposition corresponds with the laying down of the Paleozoic rocks. In the western part of the peninsula, however, as has already been pointed out, there are limestones containing Cambrian and Ordovician fossils, and as there is no known break between these limestones and the Silurian-Devonian-Carboniferous (?) rocks of this region it is assumed that the period of deposition may have continued practically uninterruptedly from the Cambrian to the Devonian or Carboniferous. During most of this time limestones were being laid down, but the intercalation of highly quartzose carbonaceous sediments, such as those now found near Mount Kwiniuk, indicates movements of the sea floor and changes in relation to the source of waste supply.

After the deposition of the Paleozoic rocks there was probably an uplift, for the next event recorded was the intrusion of greenstones, some of which formed surface flows. Such flows could hardly have taken place while the limestones were being laid down, and it is therefore necessary to believe that a part of Seward Peninsula was at that time dry land. This period of greenstone intrusion was well marked through many parts of Alaska and has been recognized not only in Seward Peninsula, but also in the northern part of the

Koyukuk, in the basin of the Melozitna, and in the Kaiyuh hills. If the extrusions of greenstone materials took place on land they must have unconformably overlain the older rocks. In the Nulato-Norton Bay region none of the effusive types were recognized, but farther west effusive character was strongly suggested by the exposures in the Solomon-Casadepaga quadrangles. In the central Yukon region the age of the greenstone intrusion is Devonian. For this reason it is possible that in the determination of the fossils from the sedimentary rocks as either Devonian or Carboniferous, preference should be given to the older rather than the younger system. In the Copper River region and in southeastern Alaska, on the other hand, a period of greenstone effusion has been described as Carboniferous or later, so that correlation by analogy is inconclusive.

With the intrusion of the greenstones there was some local or contact metamorphism of the rocks they penetrated, but the effects were slight. There was also the formation of some veins, but many of the older veins were already in the Paleozoic rocks before the intrusion by the greenstone, for in places the veins are abruptly cut off by the later rock. With the greenstone probably a little mineralization was introduced, but its effects upon the metalliferous resources of the region were slight.

After the formation of the greenstones a period of mountain building ensued in which the previously formed rocks were metamorphosed dynamically and profoundly faulted and folded. When this occurred can not be told with definiteness owing to the uncertainty of the ages of the Paleozoic rocks and the greenstones. From the evidence afforded by other parts of Alaska there are two dates to which the deformation may reasonably be assigned—one is in the late Devonian, and the other is in the early part of the Mesozoic. If the Devonian instead of the Carboniferous age of the sedimentary rocks is assumed, it follows that either of these periods will fulfill the requirements of the field evidence. If, on the other hand, however, the upper part of the deposits is Carboniferous it is evident that the period of mountain building following the deposition and consolidation of the Paleozoic sediments and their intrusion by the greenstones must have been the one occurring in the Mesozoic. No conclusive evidence on this point has been obtained, and the question must still remain an open one.

As a result of the deformation, the rocks were cleaved and folded and probably high mountains were formed. As soon as they were formed, erosion began to wear them down and to transport the material toward the sea. No clear idea is possible of how long this process continued uninterruptedly, for the only part of the Mesozoic represented by stratified rocks in this field is Cretaceous. An interruption occurred some time after the mountain building and prior to the deposition whereby igneous activity became dominant. There is no evidence as to whether during the early part of this vulcanic cycle the region was land or was beneath the sea, but for the purposes of the present report this is not of great importance.

The first recorded intrusion of this period was the formation of diorites, which were subsequently intruded by granites, and these in turn were intruded by other diorites. Although these various phases could not have been formed within a short time of each other (for each of them had cooled and consolidated sufficiently before the next succeeding intrusion so that they broke into angular fragments), from a geological standpoint they were closely associated in age and may be considered as a unit. Evidence as to the age of these rocks is afforded only by analogy with other parts of Alaska. In the Matanuska-Talkeetna region of south central Alaska, Knopf and Paige determined the age of the great granodiorite-diorite intrusions as later than the Middle Jurassic and earlier than the deposition of the late Jurassic strata.[a] The Wrights in southeastern Alaska stated that, although the date of the major period of intrusive activity (the time of the Coast Range intrusion) was in doubt, it continued at least until late Middle Jurassic time.[b]

Although long-range correlations of this sort are clearly liable to gross errors, the absence of other data is sufficient justification for tentatively accepting the only available facts at hand. On this assumption the most reasonable age determination of the intrusives of the Darby and Bendeleben mountains is that they are Middle Mesozoic.

In the section dealing with the descriptive geology of the pre-Cretaceous igneous rocks it was stated that in the Kiwalik-Buckland divide there were ancient effusives along the flanks of that highland. It is practically inconceivable that effusive rocks of geologically the same age as granular intrusives should occur in contact with those intrusives. The granular rocks by their texture require relatively slow cooling under considerable cover. It follows, therefore, that when the intrusives of the Kiwalik-Buckland highland were injected there had been a considerable thickness of strata over the region, which was removed before the effusion of the older lavas. No precise measure of the time required for eroding the superincumbent rocks can be made, but it must have taken a long time. After erosion had exposed the plutonic rocks of the mid-Mesozoic, andesitic lavas were extruded.

During the latter part of this period this portion of Seward Peninsula, at least, must have been land. Gradual submergence occurred and marine waters beat against the shore forming a heavy conglomerate which, as time went on and the shore line gradually encroached farther and farther on the land, was buried in the deeper parts of the basin by finer sediments. At no time, however, was the water in the basin very deep, for mud-flat markings and cross bedding are observable at many places. Probably by stages more or less equal with the filling of the basin with detritus the bottom sank until a great thickness of sediment was deposited. Where the farthest encroachment of the sea on the land occurred is not known, but marine waters must have covered the larger part if not the whole of what is now Seward Peninsula. In this sea the deposits accumulated and covered the pre-existing topography that had not been effaced by the beat of the sea upon it.

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[a] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in Matanuska and Talkeetna basins, Alaska: Bull. U. S. Geol. Survey No. 327, 1907, p. 20.

[b] Wright, F. E. and C. W., Ketchikan and Wrangell mining districts, Alaska: Bull. U. S. Geol. Survey No. 347, 1908, p. 76.

The geologic age of the sediments deposited during this period is Cretaceous. As has already been stated, on page 56, the Ungalik conglomerate at the base may be Lower Cretaceous, but the upper part, or Shaktolik group, contains no fossils other than of Upper Cretaceous age. In other parts of Alaska there has been reported a pronounced break between the Upper and the Lower Cretaceous and the two are in uncomformable relations. In this province no break was noted. If, however, subsequent studies should show a period of diastrophism between the Upper and the Lower Cretaceous it would seem rather conclusive evidence that the Ungalik conglomerate is of Upper Cretaceous age, for the fossil evidence which seemed to indicate a Lower Cretaceous age is very weak. Under such conditions the Lower Cretaceous would be represented in Seward Peninsula by the erosion interval at the base of the Ungalik conglomerate.

Succeeding the period of Cretaceous deposition was the last epoch of mountain building. By this deformation enormous folds and faults were produced which must have made mountain ranges of great height. There is no direct evidence as to the time when this folding occurred. From analogy with other parts of Alaska, however, it is known that there are two possible ages to which the epeirogenic movements may be referred. In southwestern Alaska the Kenai or upper Eocene is unconformable on the Upper Cretaceous.[a] This unconformity is marked by a break in faunas rather than by mountain building, but the fact that in places the Kenai is known to rest directly upon the Jurassic indicates a long period of changes. The other period to which the great orogenic movements of the post-Cretaceous may be referred is later than the deformation of the Kenai. There is but little to show which of these is the correct correlation, for there is no Kenai in the region studied. With full recognition of this uncertainty it is believed that a pre-Kenai age for the period of orogenic movement, which closed the Cretaceous deposition, fits more of the known facts than any other interpretation. According to this hypothesis the larger outlines of the geology of western Alaska were marked out before the Kenai and the sediments of the latter period were deposited mainly on the eroded surface of the earlier rocks and mostly as fresh water deposits.

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[a] Stanton, T. W., and Martin, G. C., The Mesozoic section on Cook Inlet and Alaska Peninsula: Bull. Geol. Soc. America, vol. 16, 1905, p. 410.

After the great post-Cretaceous deformation, intrusion of granular rocks, such as those of Christmas Mountain, occurred. It is unsafe to assign a more specific age for this period of volcanism than the middle Tertiary. Whether the mountain building was closed before the intrusion is not definitely proved. The fact that some of the dikes from the Christmas Mountain mass are faulted shows either that the deformation had not entirely ceased or that the dikes were formed at a later time.

With the conclusion of the period of granular intrusions and of the great post-Cretaceous deformation, the region as a whole has been a land area subjected to erosion which has continued down to the present time. An enormous amount of erosion is indicated before the next recorded event in the history of this complex region. As a result of this erosion valleys were cut and the region was reduced from a mountainous country to one having something like the present topography. Then volcanic activity began and continued spasmodically from the later part of the Tertiary almost down to the present. The recent basaltic lavas of the Yukon and of the Koyuk and its environs bear witness to this period. As has already been pointed out some of these lavas are so recent that they overlie the gravels of the Noxapaga basin, whereas others are so much older that they stand at least a hundred feet above the present streams, which have carved their valleys through them.

Many of the lavas flow down the lowland areas of the preexisting topography. In these depressions they were consequently thicker and have therefore been less thoroughly removed by erosion. From the distribution of the residual patches it is therefore possible to reconstruct in a measure the former topography, and it is from this reconstruction that one is able to state that much erosion must have affected the structure produced by the post-Cretaceous deformation before the effusion of the lavas.

While the volcanism was in progress, erosion still continued over much of the area and the highlands were degraded and deposits were formed off the coasts. The erosion, however, did not proceed uniformly, for there were undoubtedly movements of the earth's crust whereby certain parts were uplifted and others depressed. On the whole, however, these movements were gentle, broad, regional uplifts and were not acute mountain-building deformations. Because of uplift movements the streams were at times forced to cut their channels deeper into the bed rock of their valleys, but at other times, because of depression, they found the rock floors too deep and were forced to lay down some of the waste they were transporting, and thus aggrade their courses. Changes of this sort, however, did not exercise any considerable effect on the form of the region except to reduce the relief consistently.

After erosion and deposition had been in progress for a long time a change in the climatic conditions resulted whereby glaciation of the valley type was developed in the highland areas. Apparently this event took place when the sum of the preglacial movements had resulted in the region standing relatively lower than it does now with respect to sea level and grade level. The main result of the period was to scour out the mountain valleys and distribute the waste thus formed beyond the area occupied by the ice. From fossils associated with the deposits formed at this time it seems probable that this occurred in the Pleistocene, which was also the period of maximum glaciation in other parts of the northern hemisphere.

As the vigor of glacial conditions abated, the glaciers receded into the hills and finally disappeared. A long time, however, is required for this process, as is shown by the various moraines in the Pargon Valley and elsewhere in the mountain region. All this time deposits of glacio-fluviatile, fluviatile, and marine origin were being formed in the areas not occupied by the ice where the conditions were favorable. Lava flows may also have occurred at this same time in the areas not occupied by the ice.

With the close of glacial conditions oscillations of the crust similar to those preceding the period of glaciation again become evident. It is not intended to imply that these oscillations ceased during glacial time, but the evidence is so obscured that the movements were not recognized. The general result of these postglacial uplifts has been to raise the region somewhat above the relative position it occupied during the Pleistocene. Apparently, however, the sum of the recent upward movements has not yet equaled the sum of the earlier downward movements, so that the floors of many of the larger streams are still below sea level. The general recent uplift is shown in the rock-walled shallow canyons in which many of the streams flow.

Although the late Tertiary to Recent movements have been described as resulting in certain general conditions, it should be distinctly understood that these movements were such that while depression was taking place in one part of the region uplift may have taken place in another. Hence it appears that deposits at the same elevation above or below sea level are by no means synchronous and may be entirely unrelated in origin. Contemporaneity of the various deposits can only be determined by careful and detailed investigations of the region. Inasmuch as many of the problems of economic importance are connected with the correct correlation of the different deposits, it is necessary that such correlations should be searchingly investigated and not be based on superficial examination or upon apparent similarity of factors known to be variables.

In order to summarize the history of the region as determined the table shown in figure 10 has been prepared. It is at best but a graphic representation of the facts already given, and has the disadvantage of giving an appearance of finality to the correlations, some of which the text has shown to be founded on insufficient data; for these reasons it should be regarded as a summary and should not be used independently of the text.

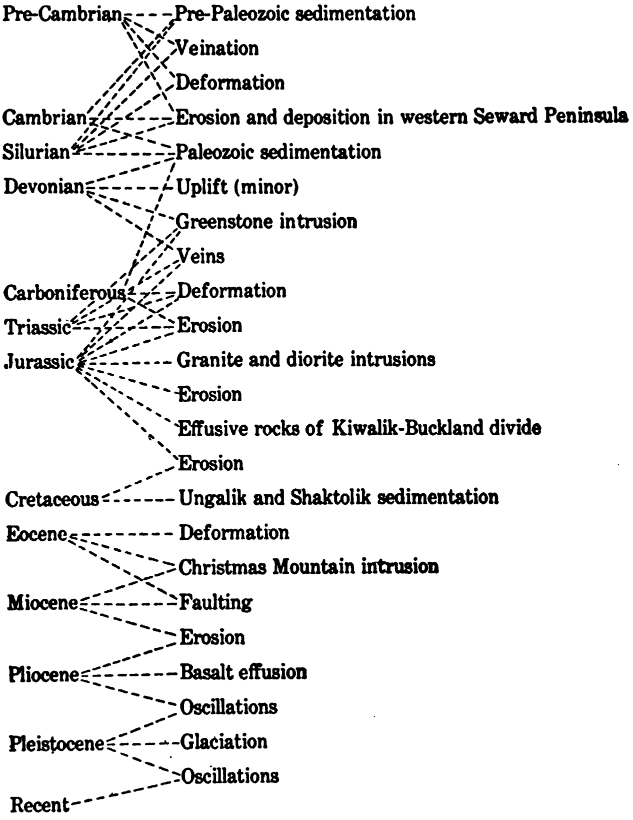

FIGURE 10.—Diagrammatic summary of geologic history of Nulato-Council region.

ECONOMIC GEOLOGY.

In the preceding description of the areal geology of the region it has been shown that east of Koyuk River the country is formed of late sedimentary rocks that are little if any metamorphosed, whereas the region to the west of this stream is predominantly one of schists, limestones, and igneous rocks. So far as has been indicated by mining in contiguous areas the metamorphic rocks are those in which deposits of gold may be sought with some promise of success, whereas the unmetamorphosed sedimentary rocks are the ones in which deposits of coal may be found.

PLACERS.

GOLD IN AREAS OF UNMETAMORPHOSED SEDIMENTS.

CONDITIONS OF PLACER FORMATION.

In the unmetamorphosed sedimentary deposits the chances of finding economically important gold deposits are relatively slight, except under local conditions. The Cretaceous and Tertiary deposits, the unmetamorphosed sediments, were formed of material eroded from the earlier rocks and deposited on the sea floor and in estuaries and marshes in essentially the same way that sediments are being deposited at the present day off the coast. Some of the present-day sediments, however, are auriferous, and it might be asked why similar placers should not be found in the older sedimentary deposits. Gold placers should occur in the Nulato-Norton Bay region under conditions similar to those prevailing in the coastal plain at Nome, but there are few places where similar conditions exist.

In order to make clear the different conditions in the two regions it is necessary to point out the salient facts concerning the productive placers of the coastal plain—for instance, those at Nome. A discussion of the character of the surface of the bed rocks is omitted as not important in bringing out the point of the following paragraph.

The known placers are not more than 3 or 4 miles from the old land from which the sediments were derived; the depth of gravel covering the bed rock is seldom over 100 feet; the gravel is as a whole fairly coarse; the rich ground occurs in ancient beaches, which mark concentration by the sea; and the country immediately adjacent to the rich placer is heavily mineralized. Consider the physical and geographic conditions which these facts entail. First, the short distance from the ancient shore line suggests that the gold did not travel far seaward from the place where it might have been formed. This is, of course, a conclusion which would have been reached by anyone accustomed to the action of gold in a sluice box. It might be safely assumed that in general the farther from the source the less gold there would be, other conditions being equal. Evidence of the proximity of the placer deposits to the old land is shown by the second criterion, namely, that the depth of gravel is seldom over 100 feet. This condition, like the preceding, is valuable in establishing the nearness of the gold to its source. The third fact also is of value in further establishing this conclusion, but it is also important as showing that the agencies by which this material was transported were of sufficient strength to permit considerable sorting of the gravel and thus to allow concentration of the particles of gold. As the coastal plain placers are found along old strand lines it follows that in order to make a deposit of economic importance it is necessary to have a marked concentration of once disseminated particles. It is, of course, unnecessary to have this concentration effected by the sea, for streams would do it equally well, as is shown by the numerous creek placers. Perhaps the most important condition which must be fulfilled in order to make a rich placer is the presence of a highly mineralized area in the more or less immediate vicinity. Without this, the other conditions are ineffective.

It has also been pointed out by others that certain physiographic conditions are essential for the production of placers, such as long continued subaerial erosion followed by rapid sweeping off of detritus by revived drainage. As the physiographic history of northwestern Alaska has not yet been worked out in sufficient detail to permit the application of this criterion it can not be critically applied in this discussion.

If now the Nulato-Norton Bay region is considered in the light of the premises enumerated above it at once becomes evident that few of its conditions are analogous to those enumerated. It is true that there are places where the Cretaceous basin is in immediate contact with the old land. This has been proved by the extension of the basal conglomerate from near the Tubutulik northward along the east side of the Buckland-Kiwalik divide. The conglomerate was noted also by Mendenhall[a] on the Kobuk, from which place it swings southeastward. It was recognized, although not correctly correlated, by Schrader on the Koyukuk and by Dall, Collier, and Spurr on the Yukon, and was correctly correlated by Maddren on the Yukon near the Melozitna.

In the belt occupied by the heavy conglomerate the deposits were certainly near enough the shore to permit the formation of placers, but the physical conditions under which this conglomerate was deposited do not seem to have been well suited to the unlocking of gold from bed rock. Instead, the bowlders were riven from sea cliffs and were subjected to trituration rather than to decomposition or disintegration, and whatever gold may have been in the rocks was so abraded before it was deposited that it undoubtedly formed flour gold, which would be much more widely disseminated than flake or shot gold. Furthermore, over a considerable part of the region where the basal conglomerate was seen by the survey party the country rock forming the old land shore line against which the sediments were deposited consisted of limestones and igneous rocks. So far as is known from a careful study of the known placer camps farther west, practically no gold is found in the limestones and none is known associated with the granites or other igneous rocks. It will be seen therefore that in the shoreward portion of the metamorphic area the important condition of near-by highly mineralized country rock from which the sediments were derived is wanting. It is believed, therefore, that search for commercial placers, although not entirely out of the question in the conglomerate area, is to be discouraged, unless the field evidence shows the existence of conditions other than those generally encountered in the basal member.

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[a] Mendenhall, W. C., Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska: Prof. Paper U. S. Geol. Survey No. 10, 1902, pp. 39–41.

Over the greater part of the Nulato-Norton Bay area it has been shown that the lower member marking proximity to the old shore line is not exposed. It seems probable that through this part of the region the deposits are much higher geologically. From the physical character of the sediments and from the structures observed, such as cross bedding, it seems certain that the higher geological members were deposited in relatively shallow water. This fact, however, does not mean that the deposits were near the old land of metamorphic rocks. Figure 11 shows in diagrammatic manner the conditions believed to have prevailed in the Nulato-Norton Bay region. The metamorphic rocks to the left in the figure may be taken to represent the schists of Seward Peninsula, and those to the right the rocks near the Melozitna; the intervening area is the Nulato-Norton Bay region at the beginning of Cretaceous deposition, with sea level indicated by the line AA. At this stage conglomerates were laid down close to the shore of the old land and sandstones and shales toward the center of the basin. Gradually depression took place and continued at such a rate that the surface of the deposits was always within a short distance of sea level. It is evident, therefore, that if this depression continued until the surface of the deposits and the sea level stood at the line BB, no part east of C as far as D had ever been close enough to the metamorphic area, which is assumed to have been the source of mineralization, to have received any notable amount of gold. Consequently, in this part of the region, unless subsequent folding exposed rocks at the surface outside of the part included within the

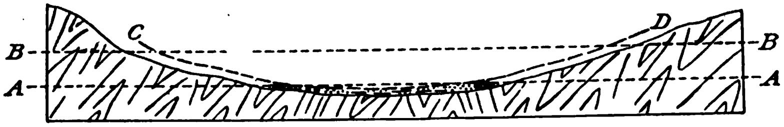

FIGURE 11.—Diagrammatic cross section of the Nulato-Norton Bay region during Cretaceous deposition.

line CD, the probability of finding auriferous deposits is slight, and then only if the old land area from which the sediments were derived was sufficiently mineralized to afford placer gold.

It has been the object in the preceding paragraphs to point out that on the whole the chances of finding gold in the area of unmetamorphosed rocks are slight. From the fact that only under exceptional conditions are valuable deposits likely to be found it seems that the ordinary prospector for gold should be warned against spending much time in the region east of Koyuk River. Not only does this conclusion seem sound from a theoretical standpoint, but it was learned from prospectors on the Inglutalik that they had been from that river eastward to beyond the Gisasa and had not been able to raise a single color of gold.

It is not the purpose of this warning, however, to assert that no gold will be found in the region, for there are three conditions under which deposits may be found. The first of these conditions, already described, is that the unmetamorphosed sediments considered may have been originally deposited at no great distance from the shore of a mineralized area of metamorphic rocks. Such deposits might be found at several places, even in the middle parts of the basin, if subsequent deformation brought the underlying rocks up to the level of erosion. As an example of this condition may be cited the area of metamorphic rocks which appear between Kwik and Koyuk rivers.

The second condition which might permit the formation of valuable gold placers in the Nulato-Norton Bay region is long continued concentration of the material, either by streams or by the ocean. Concentration of this sort may have been effected either during the time the sediments were being deposited or at a much later time. Throughout the period occupied by the deposition of the sands and gravels the region was apparently undergoing almost uninterrupted depression, so that, although there was sorting by water, it was nowhere so effective as it would have been if the region had been one of alternate erosion and deposition, as the coastal plain at Nome has been. In other words, the ancient placers at Nome seem to have been subjected to at least two periods of concentration, whereas the deposits of the other region seem to have undergone but one. Since consolidation, the sandstones and shales of the Cretaceous have been eroded by the streams and a present day concentration is being effected. Some of the reported gold placers in the Yukon basin are probably due to this sorting, but they may have been formed by original sorting before the consolidation of the sediments, for little is known about the deposits.

The third type of locality where search for gold placers or lodes in the area of nonmetamorphic rocks would be warranted is at those places where mineralization has occurred since Cretaceous times.

Such places are, so far as known, closely associated with the areas of intrusive igneous rocks. The effusive rocks or lavas of Tertiary-Recent age do not seem to have brought any valuable minerals, and therefore placers or lodes due to post-Cretaceous mineralization are not to be sought in those areas where only these rocks occur.

Intrusive rocks later than the Cretaceous have been noted at but two places, although a more detailed investigation of the area undoubtedly might result in discovering others. The two places where these later granitic rocks have been examined by the Survey party are at Christmas Mountain, east of Ungalik River and at Bonanza Creek. From reports of prospectors it seems that the placer-bearing gravels of Anvik River may have been derived from a similar area of intrusive granitic rock, although too little is known of the geology of the country to advance this interpretation more than tentatively. Spurr[a] in his summary of the occurrence of gold in southwestern Alaska says:

> The gold in this region is by no means so abundant as it is along the belt of the Yukon geanticline, where the ancient schists with their inclosed quartz veins are found. The mineralization of southwestern Alaska is of a later date and not so intense or widespread. Within the area examined by the writer's party last summer (1898) the Tordrillo Mountains are undoubtedly the chief seat of mineralization, and this appears to be directly dependent upon the fact that these mountains have also been the chief seat of intrusion of igneous rocks.[b]

PLACERS OF THE BONANZA CREEK REGION.

Bonanza Creek is the only stream between the Koyuk and the Yukon where placer mining has been successfully carried on. This creek is only about a mile long, but values have been found almost the entire length of its course, and, from the character of the gold, they seem to be of distinctly local origin. Gold was originally discovered and staked on this creek in 1899 by Thomas Moon and his partner. The absence of water and the boom that the Seward Peninsula placers were having prevented any considerable development for the first few years on Bonanza Creek. After the lower claims had changed hands several times they were bought by the Nelsons, who have since been the most industrious miners there. Other miners have held ground on No. 2 and No. 3 above the Discovery claim, and some work has been done for the last two or three years. It is hard to realize that during the boom days of this camp nearly a hundred men rushed to the creek, and several road houses and three or four saloons were in operation, for now the creek is practically deserted, and only four or five white men are living there.

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[a] Spurr, J. E., Reconnaissance in southwestern Alaska in 1898: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, p. 261.

[b] It is extremely doubtful if the intrusives of the Tordrillo Mountains are post-Cretaceous, as the sedimentary rocks they cut are Jurassic or older.

At first the creek claims were the ones from which the values were obtained. On the lower claim the pay streak was 400 feet wide, but it narrowed upstream and at the northern line of No. 1 above Discovery the width was only about 75 feet. The gravels are typically river wash in form and consist of material from near-by rocks, although some of the pebbles were undoubtedly derived from higher level gravels which were not of local origin. Bed rock is a much shattered black slate or shale, on the whole rather thinly laminated and not so quartzose as the black quartzitic slates of the Paleozoic section. The slates are cut by igneous rocks of the granite family. An exposure of one of the intrusive dikes occurs a short distance north of the cabins at the junction of Bonanza Creek and the Ungalik. Here the dike is apparently about 10 feet wide and shows by its undeformed character that it was injected subsequent to the period of folding and faulting of the slates. It trends obliquely to the slates, having a strike of N. 5° E. and stands vertical. It is heavily iron stained in places. This iron is probably derived from the decomposition of sulphides, some of the unaltered material showing pyrite in microscopic sections.

Above the stream on the northeast side of the valley is a bench on which gravels have been found that are highly auriferous. After the exhaustion of the creek gravels attention was turned to this high-level ground, and satisfactory returns have been obtained from it. Aneroid readings give the elevation of the bench as about 80 feet above Bonanza Creek at the cabins, but some gravels have been found up to an elevation of 150 feet above the stream. The gold on the benches is medium coarse and of a dark reddish color. None of it is black gold. Several nuggets were seen that had small pieces of quartz attached. From the owners it was learned that the largest nugget taken from this creek was worth about $21. The value of the gold is high—that from the lower claim being reported as worth about $19.25 an ounce, and some from higher up on the creek and not from bench ground assaying from $19.05 to $19.15 an ounce.

Concentrates from the bench ground show a good deal of magnetite or black sand. Some of the fragments of this mineral were as much as one-fourth of an inch in length. Together with the magnetite is also ilmenite or the oxide of titanium and iron, which is nonmagnetic. Garnet or the so-called "ruby" sand is practically absent in all parts of the creek. This was to be expected, for none of the rocks in the neighborhood show any such development of this mineral as is the case in the Seward Peninsula placers. Some float pieces of antimony are occasionally found in the gravels of Bonanza Creek.

Bonanza Creek has such a small supply of water that the extraction of the gold from the gravels has been a serious problem. In the early days the separation was accomplished by the use of rockers, and even during the summer of 1909 this method was still in use on some of the creek gravels half a mile or so above the mouth of the stream. The discovery of gold in the high benches called for a supply of water at considerable elevation. Ditches except of such length as to be prohibitive in cost were not feasible, and the experiment of pumping water from Ungalik River was resorted to. Wood cut in the neighborhood of the mines was used for fuel. Although no figures are available as to the cost of the water delivered on the ground, it seems that the fact that this method was pursued until the claims were worked out is sufficient proof that the owners were satisfied with the project.

The method of work was to make cuts at intervals at right angles to the trend of the old channel. In these trenches sluice boxes were placed in such manner that their lower end discharged toward Bonanza Creek. The abrupt cliff that occurs at the edge of the bench deposit offered particularly favorable topography for the discharge of tailings on the lower ground so that the boxes would not become choked, and this was taken advantage of. The water pumped in two lifts was delivered to the nozzles on the bench ground and the gravels and overburden were washed through the sluice boxes. After the gravels had thus been sluiced off, the bed rock was taken up by hand and cleaned. In places three feet of the rather angular blocky slate had to be picked up to recover the pay values, but over much of the bench ground it was necessary to take up only from 12 to 18 inches.

During 1909 the last of the bench and creek ground nearest the mouth of the creek was exhausted, and the boiler and pump were dismantled and put into condition to be shipped away; the lower claims may now be regarded as worked out. Good bench placer ground, however, continued from the end line of the claim, and the next upstream claim undoubtedly contains valuable deposits. During the early part of 1909 the owner of this ground was engaged in building a small ditch from the upper part of Bonanza Creek to bring water to this bench. The small amount of water available, however, makes it probable that the operations will be much hampered. The bench ground is frozen, and either a strong head of water will be required to break down the gravels or else the owners will be forced to resort to thawing.

On the fourth claim above the mouth of Bonanza Creek little work was accomplished during 1909 and that mainly of a prospecting character. The unusually dry season made this part of the stream practically dry by the middle of July, and the only gold taken out was by means of rockers. At this place specimens of gold in a black graphitic slate were seen. This occurrence suggests that the carbon, which is abundant in the slates, may have been effective in causing the deposition of the gold.

At the mouth of Bonanza Creek some gold has been found in the gravels of Ungalik River. Several rather shallow holes have been put down in the river flats, a few score yards north of the mouth of Bonanza Creek, and good prospects have been reported. On the whole, however, the tenor of the gravels of Ungalik River is low, and, although occasional 5-cent pans have been found, the average indicated is so low that the ground could not be worked without labor-saving devices capable of handling large quantities of gravel at a low cost. The gold is reported to be irregularly distributed; rich pockets separated by intervals of barren ground are to be expected, which condition is not one calculated to encourage the development of large undertakings.

The other placer where post-Cretaceous mineralization apparently associated with igneous intrusions has been reported is at Christmas Mountain. Scores of lode claims have been staked on this mountain, but, with the exception of a little sulphide mineralization, few indications of profitable veins have been disclosed. In spite of the apparent absence of lodes that would warrant extensive development it is believed that there is a disseminated mineralization in the vicinity of this mountain that might justify search for placers in the neighborhood. From the reports of prospectors it was learned that colors of gold had been found in the gravels of many of the streams heading in this mountain and draining either into the Ungalik or the Shaktolik. Several placer claims have been staked on Christmas Creek, which enters the Ungalik 3 to 4 miles north of camp A16, but no mining has been done. It seems probable that the inaccessibility of the region would make it unprofitable to work any but a rather high grade placer at the present time at this place.

It is further reported that stibnite (antimony sulphide) float has been found on the divide between the Shaktolik and the Ungalik, about 4 miles northeast of Bonanza Creek, on the slopes of Christmas Mountain. This mineral was not found at this place by the Survey party. Its presence would indicate that there has been a good deal of mineralization and would show that the sulphide mineralization already noted may have introduced many different minerals.

In the same general region, but not definitely associated with intrusive igneous rocks, are streams that are said to have some auriferous gravels; the geology of these places is too indeterminate at the present time, however, to warrant even a suggestion of the origin of the valuable minerals contained. Garryowen Creek, a tributary of the Inglutalik heading in the Ungalik divide, is reported to yield colors of gold. Negromoon Creek, which joins the Inglutalik from the west upstream from Garryowen, also shows gold-bearing gravels. The values, however, on both these streams are so low that they are of no commercial significance at the present time and can not be worked under existing conditions. No adequate prospecting has been done on any of these streams, and it is therefore impossible to make even an approximation of the tenor of the gravels.

GOLD PLACERS IN AREAS OF METAMORPHIC ROCKS.

DISTRIBUTION.

As the metamorphic rocks are older than the nonmetamorphic rocks they have been subjected, broadly speaking, to at least the same number of periods of mineralization as the latter plus whatever number occurred before the laying down of the Cretaceous sediments. It is, of course, realized that mineralization may be distinctly local and may affect one region and not another, and it is not intended to assert that the richness of a region is necessarily dependent upon the number of periods of mineralization it has undergone, although, according to the law of chances, such a generalization is sound. This view receives corroborative support from the field evidence, for in most of the Seward Peninsula placer regions there were at least two periods of vein formation, during each of which gold lodes were made, whereas in the area of unmetamorphosed sediments only one period has been recognized.

Valuable gold deposits have been mined most extensively in Seward Peninsula where the metamorphic rocks are most abundant, and it is believed that regions underlain by them are the most promising areas in which to prospect for new placers. In general, the richest placer areas are near the contacts between the heavy overlying older limestones and the underlying quartz chlorite schists. So far as known, the intrusive igneous rocks older than the Cretaceous are not auriferous, and neither are the more recent lava flows. Therefore, areas deriving their surficial deposits from such rocks are not likely to afford valuable placers.

Several of the various placer camps located within the area covered by the map of southeastern Seward Peninsula were not visited during 1909. It has been thought desirable, however, to summarize the investigations made during previous years in order to gain a more comprehensive idea of the mineral industry as a whole, rather than to omit districts so important as Council and Bluff simply because they have been already described. Consequently, to complete this part of the report it is necessary to refer to the published reports of Brooks, Moffit, Collier, and others. In the treatment of the gold placers of the areas of metamorphic rocks a geographic order will be adopted. The placer deposits of a single river basin will be treated from the mouth toward the head of the stream. The various river basins tributary to Norton Sound will be described from east to west, beginning with the Koyuk, and then will follow descriptions of the various basins emptying into Kotzebue Sound from Buckland River westward.

KOYUK RIVER BASIN.

In the Koyuk Basin no gold placers are now being mined and commercial mining has been done in but few places in the past. Colors of gold have been found on many of the streams and many attempts at mining have been made in the region, but so far without sufficiently encouraging returns to keep a permanent force on any of the streams.

About a mile west of camp B17, at the mouth of the Koyuk, there is a black limy schist and limestone that occurs east of a lighter-colored schist, the dip of both being practically vertical. On the beach at this place and extending for a considerable distance both east and west are many large angular pieces of quartz float that suggest vein material. Pans of broken-up material from the schists near this place show a number of very small colors of worn placer gold. From a prospector living near the place it was learned that 1-cent pans had been found, but the small returns were not sufficiently encouraging to warrant any considerable expenditures of either time or money.

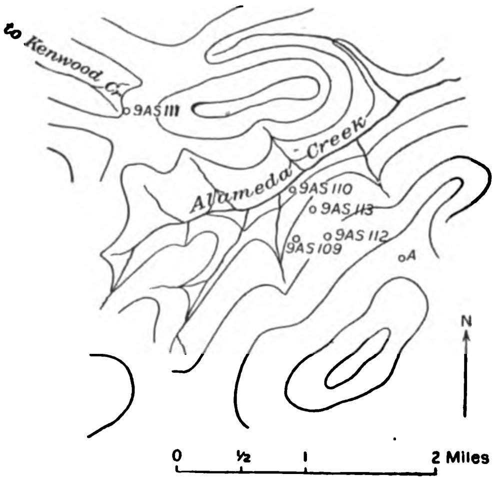

FIGURE 12.—Sketch map of Alameda Creek.

Alameda Creek, a small tributary to the Koyuk from the west, joining the river a short distance below the mouth of East Fork, was visited in the early part of August. Although no active work was in progress the problems that have been raised by earlier prospecting are such as to attract the attention of the geologist. Figure 12 shows the headward portion of this stream with the location of the different prospect holes that have been sunk. The elevations are only approximate, as the weather was so changeable that an aneroid was of no assistance.

At locality 9AS109 south of Alameda Creek a shaft 192 feet deep was sunk all the way through well-rounded, predominantly quartz gravel. The upper part of the gravel is whitish, with black quartzite pebbles and some glassy lava; not many pebbles of the latter material were found. Midway in the shaft the gravels are more yellowish and more iron stained than in the upper part. In the lower part of the hole the fine material is of a greenish-white color but is otherwise similar to that above. On reaching a depth of 192 feet the miners were forced to abandon the shaft, as they encountered a great deal of water. This condition suggests that they were approaching bed rock. This conclusion receives some support from the fact that in the bottom of the shaft pieces of ancient lava, probably the country rock here, became more numerous.

It is reported that in the general gravel section cut by the shaft a few thin sedimentary layers were found that gave fairly good prospects. A pan of the gravel from the dump which was said to have come from near the top of the shaft gave two small colors. Samples from the gravels said to be near the bottom of the shaft showed also minute specks of gold. In the concentrates from the same part of the section there was a good deal of black sand, but garnet was practically absent. A good many pieces of undecomposed sulphides were also recognized in the concentrates. Within 100 feet of the shaft a pan from the surface gravels directly under the grass roots showed several bright colors of gold, some magnetite sand, and ilmenite.

Nearly due east of the last locality and at an elevation about 100 feet higher another shaft has been sunk (locality 9AS112). The depth of the shaft is somewhat over 70 feet and it has not reached bed rock. The material on the dump consisted mainly of well-washed white quartz gravel, with some pebbles of black quartzite and red lava. Twenty-five feet east of this hole and at a slightly higher elevation a shaft had been sunk 45 feet without reaching bed rock. The material on the dump at this shaft was more sandy and the pebbles were smaller than at the shaft at locality 9AS112.

Northward down the slope at locality 9AS113 another shallow shaft has been put down. It was only about 15 to 20 feet deep, and in it no gravel at all was reported.

On a low bench on the south side of Alameda Creek, at an elevation of less than 10 feet above the water, there is a caved shaft (locality 9AS110). This was originally 32 feet. deep and reached bed rock, which belonged to the group of ancient igneous rocks. There was a great deal of well-rounded quartz gravel, but as a whole the material on the dump was much darker than at locality 9AS109, and there was a much greater proportion of lava fragments. The prospectors who sunk this shaft reported that the values were found entirely on bed rock and that the lower gravel went about 1 cent to the pan. Upstream from this shaft the present gravels of Alameda Creek are reported to carry no gold, whereas northeast, or downstream, the creek gravels yield about 7 cents to the 10-pan bucket. A mile and a half downstream, however, even this amount of gold disappears and the gravels are barren. From these facts it would appear that the present creek may derive its gold from the earlier channel. It should be remembered, however, that if the values occur mainly on bed rock in this channel the bottom is still below the level of Alameda Creek, and therefore the reconcentration has not affected the richest portion of the old channel.

Directly across the creek and at the same elevation above the stream as locality 9AS110 a shaft 12 feet deep has been sunk to bed rock. The bed rock at this place also was dark, much fractured, fine-grained lava. A pan of gravel from the dump at this place showed an abundance of green lava sand with numerous hornblende crystals. Several well-rounded garnets were also noted.

A mile and a half west of this shaft and on one of the small tributaries of Kenwood Creek some further prospecting has been done to try to locate the northwest continuation of the old channel. At locality 9AS111 there is a shaft 24 feet deep, now badly caved. The material on the dump is nearly all angular, almost completely decomposed rock, which seems to contain some rounded black pebbles. The material is so badly changed that it is impossible to assert definitely whether it represents a recent slightly consolidated gravel or a more ancient sandstone or fine grit. It was claimed by the prospectors that bed rock was reached in this shaft and samples of the material supposed to be from the bottom of the hole showed thin quartz and calcite veins with decomposed material between. Some of the quartz was much slickensided.

Forty-five and sixty-five paces west of locality 9AS111 were two other prospect pits at a slightly lower elevation than the one last described. The western one showed undoubted gravel on the dump, some of the pebbles being 3 to 4 inches in diameter. There were very few white quartz pebbles, the greater number being of black quartzite. There seems to be little room to doubt that this is a portion of the same deposit encountered in the deep shaft at locality 9AS109. It is unfortunate that the depth to bed rock has not been determined at the two places, for it might afford information either as to the direction of the old drainage or as to the amount of deformation since the cutting of the channel.

On the broadly open saddle, 1½ miles southwest of locality 9AS109, quartz gravel is reported to be abundant, and it is believed that this low pass may mark the southern continuation of this channel. On this assumption a party of three or four men was engaged in prospecting during the winter of 1909–10. From a recent letter it seems that little was accomplished at this place during the winter, and although seven holes from 18 to 24 feet deep were sunk their location is not sufficiently explicit to show the relation to the surrounding topography. It was stated, however, that they found but little of the well-rounded wash noted at locality 9AS109. In several of these holes colors of gold were found, but apparently not enough to warrant further prospecting. It should be pointed out, however, that even if this be the old course of the valley it does not follow that the gravels will be commercially valuable, for, as has already been noted, so far as prospected the gravels in the deep hole on Alameda Creek are not sufficiently gold bearing to be mined at the present time.

Not enough facts are yet available for more than a tentative interpretation of the conditions under which the old channel was formed. It is evident from the presence of lava in the gravels of the channel filling that the channel was carved and occupied by a stream later than the effusion of the recent lava. It seems probable that a rearrangement of drainage may have resulted from the extrusion of the tongue of lava which occupied the low country between Koyuk and Buckland rivers and flowed down the present Koyuk Valley below East Fork. This may have resulted in turning the lower part of the Koyuk out of its former course and allowing it to cut its gorge. After the gorge had been eroded, either by change in the relation of the land with respect to sea level or by capturing, the old valley was filled and the stream was so diverted that it took up a course parallel with the tongue of lava that flowed down the Koyuk Valley. It eroded the lava, thus etching out and uncovering its former valley, in which it now flows.

In regard to the origin of the gold found in the old valley gravels there is some question. Alameda Creek is near the area of metamorphic rocks, and the presence of a great number of pebbles of vein quartz in the gravels suggests that they at least have been derived from the quartz stringers in this series. If this vein quartz has been derived from this source there is a strong presumption that the gold has also come from the same place. On the other hand, it should be noted that there are indications that some of the ancient lava is mineralized. A shallow prospect pit has been sunk on a ledge of amygdaloidal trap outcropping on the divide between the Koyuk and Alameda Creek at A, on figure 12. Assays made at Nome of material from this pit are reported to have given as high as $3.72 in gold per ton. The rock shows no macroscopic mineralization, and considerable doubt is felt of the accuracy of this determination.

Kenwood Creek, which enters the Koyuk from the south above East Fork, has been prospected near the head, as already noted, and a little work has been done also on the lower part. Two prospectors, who were reported to have found good prospects at this place several years ago, went to the lower part of Kenwood Creek during the summer of 1909. The low water prevented their getting upstream far enough with their boat and they returned. It is probable, however, that bed rock through the lower part of the creek is deep and difficulty with water will be experienced.

On Willow Creek, which enters the Koyuk from the south above Kenwood Creek, there are signs of former prospecting, but the stream is now deserted. McPherson says that at the time of his visit (1907) location notices were seen, which showed that the prospecting had been done about five years before.

Peace River is one of the northern tributaries of the Koyuk west of East Fork. About 12 miles above the mouth it forks, and near this place some prospecting was done during the winter of 1908. Two shafts were put down on the east bank of the river, but they were so badly caved that only the upper 3 feet or so was visible. This part of the section shows brown, irregularly bedded sands of even texture, having in general a dip toward the west—that is, toward the stream. The material on the dump is fairly well-rounded river wash, consisting almost entirely of igneous rocks with some red, iron-stained gravel of the same nature. The eastern of the two holes was probably not more than 15 feet deep, but the other may have been 25 feet deep. Some material put aside as though it were the pay gravel was a greenish-brown sand.

About 100 yards east of this place and on a slightly higher bench there is another shaft now filled with water. This pit was probably not more than 5 or 10 feet deep. From the material on the dump it appeared that the gravel is not so well rounded and there is much more mud mixed with the sand. The upper 2 or 3 feet, which was the only part visible, instead of consisting of sands as in the western holes, was entirely formed of muck. From prospectors it was learned later in the season that some gold had been found in these holes, but not enough to warrant further exploitation. It was currently reported that one piece of gold found there was worth 4 cents, but this was the largest piece. The presence of gold at this place suggests the possibility of some of the ancient lavas having been more or less mineralized, but the evidence is not sufficiently definite to preclude other sources of origin.

Mendenhall notes that in 1900 Big Bar Creek had been prospected and a mining district established there. He was unable to learn the success of the operations, but the fact that in 1903, when this region was visited by Moffit, no work was in progress and the creek was deserted shows that the gold tenor of the gravels must have been too low to make mining profitable.

A tributary creek farther up stream and heading in the hills near the low pass into Death Valley and the upper part of the Koyuk basin is mentioned by Mendenhall as follows:[a]

> Just above the camp of September 5 another tributary enters from the south carrying only schistose pebbles. These, however, are very calcareous. Most of the streams which enter the upper course of the river from the north lie

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[a] Mendenhall, W. C., op. cit., p. 213.

> without the lava belt, but the schists here have not the aspect of the gold-bearing members. At Cheenik in the fall we met prospectors who had been up the river and reported finding colors all along its course.

Moffit in 1903 reported no mining in this part of the river basin, and no signs of recent work were seen by the party in 1909.

KWIK RIVER BASIN.

No mining was in progress during 1909 on any of the streams in the Kwik River basin, and so far as could be learned little or no prospecting has been done in the past in this area. On the head of Quartz Creek, about 3 or 4 miles east of camp C3, there were some old claim stakes and some sluicing had been done several years ago. McPherson, who visited this region in 1907, noted that he found location notices of about five years previous date on this creek.

TUBUTULIK RIVER BASIN.

During the time that the survey party of 1909 was in the vicinity of the Tubutulik no prospectors were seen and no evidence of any recent mining was observed. Practically the only thing that is known about the mining in the basin is furnished by the report of Mendenhall,[a] in which the following statements are made:

> This stream, while farther from the known productive districts than the Fish, was the object of considerable attention during the season of 1900. The surface gravels of the river bars gave colors quite as heavy as those on Fish River, wherever a pan was washed out—at least as far up as the granite area. We had no reports from the head of this stream and did not have an opportunity to examine it ourselves, but the area drained by it is not particularly promising. Mr. C. C. Alexander and members of his party, who had been prospecting on Chukajak and Vulcan creeks during the fall of 1899 and the summer of 1900, report the finding of coarse gold early in their work on the former stream, but more thorough development did not fulfill the promise of this first find. Reports of favorable prospects here had, however, reached Golofnin Bay and Nome, and a small stampede toward the Tubutulik resulted. When we left the river, late in August, many outfits were reaching the field. Reports toward the end of September did not tend to confirm the earlier accounts of rich strikes there.

It was reported that some mining was done several years ago on the next stream above Lost Creek. According to Mendenhall the name of this creek was Admiral, but the claims were described as on Camp Creek. It seems probable that the two names are applied to the same stream, but which is correct could not be determined. From the character of the bed rock near this stream it would appear that the geology is complex and that the older schists form the lower part of the valleys, so that it is presumed the gold was derived from them. Placer mining on Camp Creek was carried on by means of horse scrapers, but the absence of any recent work in the vicinity seemed to show that the returns were not satisfactory. From the strong evidence of glaciation of the valley type in many of the streams heading in the Darby Range and entering the Tubutulik from the west it seems unlikely that any rich placers will be found in that part of the basin. The eastern boundary of the basin in the southern part is formed of the Ungalik conglomerate so that strong mineralization is not to be expected from it. Farther north the eastern part of the Tubutulik divide is formed of the Paleozoic limestones, and these are not promising rocks from which to derive placers. It is felt, therefore, that a large part of this drainage basin is not particularly favorable for commercially important placers.

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[a] Mendenhall, W. C., op. cit., p. 212.

KWINIUK RIVER BASIN.

Practically the whole of Kwiniuk River and its tributaries flow in valleys carved in the igneous rocks that make up the Darby Range. So far as is known these rocks are but slightly mineralized. Consequently there is but little chance that the detritus worn from these rocks would form valuable placer deposits. In the lower part of the course, where the bed rock is heavily covered by unconsolidated deposits, the character of the country rock is not evident, and the more mineralized schists may occur. If this is the case, there is some possibility, where concentration has been effective, that placers may be discovered. The depths of covering and the question of handling water would make the development of such placers difficult.

FISH RIVER BASIN.

MAIN STREAM.

The main Fish River basin has not been important as a placer district, although the tributaries of the Niukluk, its longest western branch, have produced more gold than those of all the rest of the region. The name of the principal town, Council, will be used to designate this placer region in order to distinguish it from the rest of the Fish River basin. According to Mendenhall[a] Fish River carries gold from its mouth to the northern end of the gorge. Throughout the lower part of the river the colors are very light, but they become heavier in the constricted part of the valley, where the stream crosses the belt of limestones and schists. Opposite the mouth of Anaconda Creek, as the lower part of Pargon River is called, pans taken from the broken rim rock yielded from one-half a cent to 1 cent each. According to the same author prospectors found nothing in the upper flats of Fish River, and so far as reported the streams flowing out of the mountains to the north do not yield colors.

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[a] Mendenhall, W. C., op. cit., p. 212.

From the geologic description of the northern and eastern part of the Fish River basin it is seen that the rocks are schists and limestones, which appear to be the same as the rocks in some of the placer regions, except that the schists contain much greater quantities of biotite. Veins are equally abundant in both types, and it is believed that the absence of placers may be explained in part by the valley glaciation that has scoured out the water-sorted deposits from most of the valleys heading in the Bendeleben and Darby mountains. This process has scattered the deposits, which may have existed in the valleys prior to this erosion. Information on the subject is still too meagre to allow a final judgment as to the reason for the absence of placers in this part of the basin, but it is believed that the physical history rather than the lithologic character is responsible for the apparent absence of placers.

COUNCIL REGION.

Placer gold has long been known in the region around Council, for it was reported by members of the Western Union Telegraph Expedition in 1865, and in 1892 John Dexter is said to have notified members of the silver-lead mining company that he had found gold there. It was not until 1896–97, however, that the discovery of Ophir Creek, the richest one in the Council district, was made by Mordant, Melsing, Libby, and Nelson. Although, apparently, gold was found at that time, it was not until the spring of 1898 that the district was organized and active placer mining begun. So valuable have the placers turned out that in 1903 Collier estimated that the gold output up to that year was between $5,000,000 and $6,000,000.[a] Since that time $2,000,000 to $3,000,000 more has been taken out, so that this camp has been second in production to that of Nome.

The productive creeks in this so-called Council region from southeast to west are Fox, Mystery, Melsing, Ophir, Goldbottom, Camp, and Elkhorn creeks. All except Fox Creek are tributaries of the Niukluk, and Fox Creek joins Fish River less than 4 miles below the Niukluk.

Fox Creek has never been a rich creek. The only valuable ground was on a small tributary known as I. X. L. Gulch, and on the main valley at the mouth of this stream. At this place, according to Collier,[b] about 2 ounces of gold were taken from about 4 cubic yards of pay dirt. A little prospecting has been done here in every year since 1906, but the production is practically negligible.

Collier[c] reported that on Mystery Creek, 1 mile from its mouth, $6 to $8 nuggets have been found. Part of the gold was bright and part was rusty, but all is rough and angular as though derived from near-by sources. On Mud Creek, a small side stream from the west, one claim was operated in 1903. The gold here, according to Collier, is found both in the gravel and to a depth of 3 or 4 feet in crevices of the bed rock. It is very rough, spongy, and somewhat rusty, and is coarse and easily saved. Near the mouth of Mystery Creek a hole 102 feet deep was sunk, but no values were found. In 1907 and for the succeeding two years there has been mining on this creek, but the production was small though the returns were commensurate with the amount of time spent.

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[a] Collier, A. J., and others, The gold placers of parts of Seward Peninsula, Alaska: Bull. U. S. Geol. Survey No. 328, 1908, p. 236.

[b] Idem, pp. 237–238.

[c] Idem, p. 240.

Melsing Creek was one of the first creeks on which gold was discovered, and it has been a constant though small producer ever since. According to the 1900 report, 40 men were engaged on the creek. Collier estimates that up to 1904 about $50,000 had been taken from this stream. The auriferous gravels seem to occur only below the mouth of Basin Creek. From this part of the creek the small pieces of gold are reported to be nearly all smooth and bright, whereas the larger ones are rusty. Richest concentration occurs on a clay layer. At the mouth of Basin Creek the gold is found throughout the gravel, but is most abundant on and in bed rock. Collier states that the average yield per man per day in 1903 was about $50.[a] One of the nuggets examined by him from this claim showed a small, square hole filled with hydrous iron oxide, probably the mould of a pyrite crystal associated with the gold.

In 1906 there had been four parties of 3 to 10 men each on Melsing Creek below Basin Creek. In 1907 a steam scraper was built at the mouth of Melsing Creek, but delays in building prevented its running full time. Work still continued near the mouth of Basin Creek and a short distance down stream. During 1908 and 1909 work was continued on about the same scale and at the same places as in the past, and, in addition, during the last-mentioned year, some mining was done on the lower part of Basin Creek. The operations were, however, on a small scale and the production was slight.

Ophir Creek is the most important gold producer in the Council region. By 1903, according to Collier, the entire creek had been prospected, and during that year 1,000 men were at work on the main stream and its tributaries. Gradually the number of men employed has decreased, but this has been due in part to the replacement of hand labor by mining machinery. Some mining was done in 1903 at the mouth of this stream in the Niukluk River flats. These gravels are estimated to carry from 50 cents to $1 a yard in bright, nearly flour, gold. Concentrates show much magnetite and garnet, with smaller quantities of pyrite and ilmenite. This deposit was developed by a steam dredge with an estimated capacity of about 3,000 cubic yards per day. Bed rock is rather deep and the difficulty of handling the water makes mining expensive. According to Collier, the gold has been derived not only from Ophir Creek, but also from the other streams.

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[a] Idem, p. 242.

Farther up Ophir Creek the gold becomes coarser and the values per cubic yard are higher. After a short experiment on the ground near the mouth of Ophir Creek already described the dredge was moved upstream and has been in successful operation ever since. In an account of this dredge recently published by Rickard[a] it is shown that the average cost is 32 cents a yard and the average gold tenor of the gravels worked is 84 cents a yard. The low value per yard is in part due to the fact that some of the ground had been worked before by more primitive methods.

Next upstream on Ophir Creek from the dredge, hydraulic mining has been tried and some good placer has been uncovered. The ground mined is now mainly on a low bench, but in the past the creek gravels have been worked by pick-and-shovel methods with satisfactory results. Still farther upstream and only a short distance below Sweetcake Creek is the Discovery claim. It has been worked for several years but was finally exhausted by the use of hydraulic elevators. The values were in fairly coarse gold of a bright color. This claim was probably the second richest on the entire creek and it is reported that $1,000,000 was taken from it.

Sweetcake Creek was staked in 1898 and was the scene of probably the first successful placer mining in the precinct, it being reported[b] that $36,000 were taken from one claim that year. The only productive claims are on the lower part of this stream; they were notable contributors in the early days of the camp, although since 1903 little gold has been won from them. Some of the gold was angular and showed quartz attached.

Little of value has been found on the main stream for nearly 1 mile above Sweetcake Creek. At this place, however, there is creek and bench ground that has been very rich. Pick-and-shovel methods were used even in the early days and in 1907 an unsuccessful attempt was made to use a dry-land dredge, which was followed by the successful use of a derrick and horse scrapers. The pay streak in the creek was from 100 to 200 feet wide. The bench gravel near this place, according to Collier, was not well sorted.[c] The pay streak is said to run 10 to 15 cents a pan. One nugget worth $3.75 is reported by Collier to have been found here, but nearly all the gold is fine and flaky.

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[a] Rickard, T. A., Dredging on Seward Peninsula: Min. and Sci. Press, vol. 97, 1908, pp. 234–240.

[b] Collier, A. J., and others, op. cit., pp. 250–251.

[c] Idem, p. 245.

From this place nearly to the mouth of Dutch Creek the Ophir Creek gravels and benches have yielded probably nearly $750,000 in gold. In the central portion of this part of the valley the presence of limestone bedrock allows a large portion of the water to flow in subterranean channels and it is notable that the quantity of gold in the gravels decreases also. At the mouth of Dutch Creek the richest claim in the whole Ophir Creek basin was located, and, although now exhausted, this claim and the claim next below probably produced nearly a quarter of the gold won in the entire Council region. Much of the gold seems to have been of local origin, as pieces with quartz attached were by no means uncommon. On Dutch Creek little has been done and then only on the lower claims adjacent to Ophir Creek. Values are reported both in the creek and bench gravels.

Above Dutch Creek the values in Ophir Creek suddenly decrease and then gradually increase toward the northwest to within a mile or so of Crooked Creek. All of the claims between these two side streams have been mined to some extent. A mile and a half above Dutch Creek, according to Collier,[a] excavations show from 5 to 14 feet of gold-bearing gravel resting upon broken limestone bedrock, and three-fourths of a mile to the north 6 feet of sand and muck rest upon about 12 feet of gravel of which the upper 2 or 3 feet carry very little gold.

In 1903 the only other work done on Ophir Creek was near the mouth of Crooked Creek. "Here terrace gravels on the left bank were being exploited. The bedrock of the deposit is probably little above the present creek. A section showed 2 or 3 feet of muck overlying 5 or 6 feet of gravel which rested on calcareous schist."[b] No work was in progress during 1906, but near this place during 1908 and 1909 a small dredge was installed and according to local reports was giving satisfaction in handling creek gravels.

Crooked Creek has been one of the richest tributaries of Ophir Creek. Collier noted that in 1903 more men were employed there than on any one of the other side streams. Near the junction of this stream with Ophir Creek the pay streak is about 250 feet wide, but it narrows rapidly upstream. According to Collier,[c] the pay streak is reported to have been about 6 feet thick. The gold tenor of the gravels mined is estimated at $4.50 to the cubic yard. The gold is comparatively coarse and the pieces well rounded. Some are bright and others are iron stained. In the sluice boxes are found heavy concentrates consisting principally of garnet and magnetite, but including some topaz. Above the lower claim the pay streak is, in the main, not more than 20 feet wide and the bedrock is a schistose limestone.

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[a] Idem, p. 249.

[b] Collier, A. J., and others, op. cit., p. 250.

[c] Idem, p. 252.

Balm of Gilead Gulch, which enters Crooked Creek from the southwest, had gold "from the surface down, but is richest in the crevices of the limestone. The gold is rough and angular, with sharp corners,"[a] and is undoubtedly of local origin. Albion Gulch contains auriferous gravels throughout its course. In 1907 two camps were established on this stream, and a rich hillside placer was mined by hydraulicking. The difficulty of obtaining an adequate constant supply of water has much hampered developments on both of these gulches.

Above Crooked Creek the valley of Ophir Creek has been prospected, but little actual mining has been done. Near the upper end of the canyon of Ophir Creek there is a little bench gravel, which was being developed at the time Brooks visited the region in 1903. Although this work may have yielded wages, it was not highly remunerative and was soon abandoned. Further prospecting was undertaken here in 1907, but was not successful in locating placer.

From the general distribution of the values in the Ophir Creek gravels it seems evident that many of the rich placers of the stream are formed by the reconcentration of former bench deposits. At other places, however, it seems clear that the richness is due to proximity to local mineralization. Collier notes that a sample taken from the schists adjacent to some quartz stringers near the mouth of Ophir Creek contained some gold and that samples crushed in a hand mortar and panned yielded free gold. On Crooked Creek there "is a mineralized belt 12 feet wide, which strikes northwest. In this impregnated zone vein quartz is associated with pyrite. It is reported to assay as high as $8 to the ton."[b] Near this place on the divide, between Gold Bottom and Crooked creeks, there is a lode which seems to be similar to the one previously noted; it is significant as pointing to the origin of some, at least, of the Crooked Creek gold, which is very sharp and angular and in many instances has quartz attached. None of these mineralized veins have been mined, and it is doubtful whether the diffused character of the mineralization would permit economic treatment. The absence of valuable placer in the upper part of Ophir Creek, beyond the canyon, strongly suggests that the gold was not derived from the biotite schists that occur in the Bendeleben Mountains.

Farther up the Niukluk is Camp Creek. Mining on this stream was described by Collier[c] as follows:

> Camp Creek flows into the Niukluk from the south about a mile below Gold Bottom Creek. Several claims were worked on this creek in 1904. The auriferous gravel is from 50 to 100 feet wide and about 3 feet thick, with an over-

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[a] Idem, p. 254.

[b] Collier, A. J., and others, op. cit., p. 252.

[c] Idem, p. 256.

burden of about 3 feet, and is said to carry from 75 cents to $1 a cubic yard. Most of the mining was done by the shoveling-in process, but one claim was hydraulicked.

Only a little desultory work has been done on this stream within the last two or three years.

The next gold-producing tributary of the Niukluk from the north above Ophir Creek is Goldbottom Creek, with its tributary, Warm Creek. Mining began on Warm Creek in 1900 and up to 1903 the basin is estimated to have produced about $100,000. "Most of the gold is rough and iron stained, and some of it is almost black. One nugget, worth $45.10, at $16 an ounce, was found in 1902; and one worth $12.33 in 1903. The concentrates contain ilmenite, scheelite, magnetite, garnet, and some hematite and rutile."[a] Mining has been confined to the portion of the stream near the junction of Warm and Goldbottom Creeks, but colors of gold have been reported from many parts of the basin. During 1906 there was a little mining, but since then practically nothing was done until 1909, when two dredges were erected in the lower part of the valley. It was so late before the dredges were completed that their production for 1909 was slight. Mineralization on a small scale is recognized at many places, and a short distance upstream a vein on which some development work has been done was found at the contact of schist and limestone. "Near the mouth of the creek are two quartz veins, one about 3 feet wide and the other about 1 foot wide, striking N. 30° E. and standing nearly vertical."[b] As the pebbles in the placers all seem to be of local origin, it is probable that the gold is also derived from veins within the basin.

On Elkhorn Creek mining began in 1900 and was reported upon by Richardson[c] as follows:

> Near the mouth of the creek 2½ feet of gravel overlie 6 inches of clay and disintegrated bed rock. It is reported by miners that the pay streak is in patches and that the average yield of pans is 5 cents. The bench near the mouth gives colors, but has not been developed. The bed rock is mica schist, interbedded with limestone, and the strike is at right angles to the course of the stream, with almost vertical dips, giving favorable conditions for the concentration of gold. The gold is medium coarse and bright yellow in color. Some very coarse gold has been found stained with iron. The average assay shows its value to be $19.12 an ounce. Quartz is often found attached to the placer gold, and one nugget was attached to a piece of mica schist. This goes to show that it is of local origin. One nugget worth $55 has been found, and several worth from $12 to $16.

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[a] Idem, p. 256.

[b] Idem, p. 255.

[c] Brooks, A. H., and others, Reconnaissances in the Cape Nome and Norton Bay regions, Alaska, in 1900, a special publication of the U. S. Geol. Survey, 1901.

In 1903 this stream was visited by Collier,[a] who reported as follows concerning mining developments:

> Since 1900 the placers for about half a mile have been entirely exhausted, but farther up the creek work is still (1903) in progress both in the creek bed and on the benches. It is estimated that the total production of the creek up to date (1903) has been from $110,000 to $120,000.

After 1903 very little work was done on this stream, and when it was visited in 1906 it was practically abandoned and since that time mining operations have not been resumed.

BLUFF REGION.

The region around Bluff has not been visited by Survey geologists since 1906, and the following descriptions are taken from Brooks's report of his visit at that time.[b] In order to condense the account certain parts have been left out and the arrangement has been changed. To connect the retained portions words, phrases, and sentences have been introduced. So many changes have been made that quotation marks have been omitted. Gold is said to have been found at Daniels Creek in September, 1899, by William Hunter and Frank Walker. Beach placer was soon after located and within less than six months $600,000 had been taken from a strip of land less than 1,000 feet long. Meanwhile, the two lowest claims on Daniels Creek were opened and in 1900 yielded probably $200,000 in gold. Most of the production of 1901–2 came from Discovery Claim, at the mouth of Daniels Creek. Meanwhile gold had been found on Eldorado and Ryan creeks and on Swede Gulch. In 1902 a strong company was organized and has ever since been in practical control of the important placer ground. Figure 13 shows graphically many of the more important features of the Daniels Creek placers.

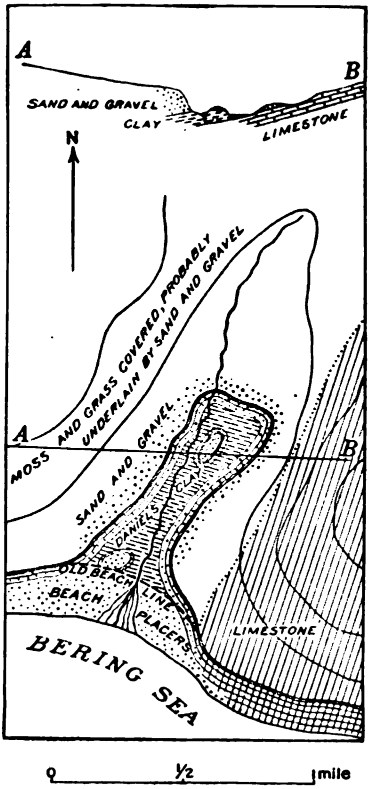

FIGURE 13.—Sketch map and section of Daniels Creek placers.

The placers are of two types, beach placers and creek placers, the former consisting of ancient and recent beaches. The alluvial material of the creeks is of two general types, that in which clay predominates and that which is chiefly sand. In many places no structure can be made out in the clays; the bedding of the sands and gravels is of the greatest irregularity, locally changing its character every few feet. The indications are very strong that the layers of clay, which in general lie near the bottom of the deposit, are formed almost in place, whereas the sands and gravels appear to have been laid down in swiftly running water. Near the head of the creek the surficial deposits consist chiefly of clay, but near its mouth sands and gravels predominate.

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[a] Collier, A. J., and others, op. cit., p. 257.

[b] Brooks, A. H., The Bluff region (in The gold placers of parts of Seward Peninsula, Alaska): Bull. U. S. Geol. Survey No. 328, 1908, pp. 283–293.

Little can be said of the distribution of pay gravels. The managers of the hydraulic mine report that in general the clay carries higher values than the sand and gravel. This is very significant, for it appears to be established that the sand and gravel have been far more concentrated than the clay. It would indicate a large gold tenor for the rock from which the clay has been derived. In any event there can be no question that the gold is very near its bed-rock source, which appears to be at the contact of mica schist and limestone.

From an examination of the Daniels Creek placers several facts are evident—first, the source of the gold is entirely local; second, where it is richest, as in the red-clay deposits, there appears to have been little sorting action by water; third, the gold is so intimately associated with mica schist débris that most probably the schist has a close connection with its origin. It is evident that the stream gradients must have been low during the period of the formation of the clay. The area was probably exposed for a long time to the agencies of weathering and an irregularly pitted land surface was produced. An uplift followed, as a result of which the carrying power of the streams was increased and the deposits of sand and gravel were laid down. At Daniels Creek this uplift gave the former level a slight tilt to the west, as is shown by the bedding of the gravels. The elevated beach deposit appears to have been formed prior to this uplift, but it would require a very detailed survey to establish this fact. The presence of gold at a depth of 60 feet near the mouth of Daniels Creek reported in 1907 may indicate either a deep zone of weathering or a buried ancient beach line. A subsequent uplift, which probably did not exceed 8 feet at the coast, exposed this older beach in part to wave action and this led to reconcentration of the gold in the gravels of the present beach.

The other creeks of the district besides Daniels Creek have been but little developed, for none of them carry a sluice head of water except early in the spring or during heavy rains. Eventually, however, they will all be hydraulicked with water from the Topkok ditch. Sluicing has been done on about half a dozen claims on Eldorado Creek, and some work has been done on Ryan and Little Anvil creeks. So far as the scanty exposures show, the mode of occurrence of the gold on these streams is similar to that of Daniels Creek, but the deposits are probably not so rich and the auriferous gravels not so extensive.

BUCKLAND RIVER BASIN.

The only stream tributary to Buckland River, on which gold placer has been found, is Bear Creek, which heads in the ancient lava hills that form the western margin of the basin. The first claims recorded on this stream were located by R. S. Hoxie, L. Tendness, and A. Barr, in August, 1901. During 1903, according to Moffit,[a] about 40 men were at work on Bear Creek and its tributaries, Sheridan and Cub creeks, but as only about $10,000 in gold was won from this basin during that year it is evident that the work was not very profitable. Figure 14 shows the location of the principal places where auriferous gravels have been found on this creek.

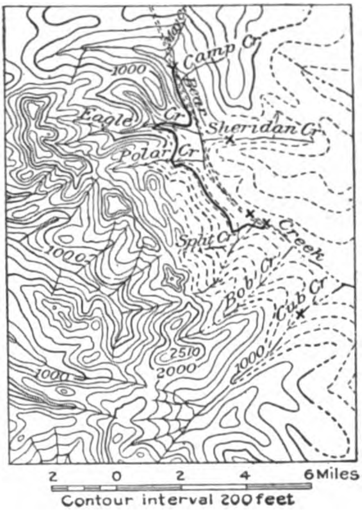

FIGURE 14.—Map showing location of placer camps on Bear Creek.

Mica schist is said not to be found in this creek, although mica does appear in the sands and gravels, which are composed largely of eruptive material, and on some of the bench claims reach a thickness of 20 feet, with several feet of muck overlying. In places on the creek a considerable quantity of a heavy red cherty rock remains in the boxes with the gold and is a source of some annoyance to the miner. This is especially true on Cub Creek. On Sheridan and Bear creeks the gold is mostly on bed rock, differing in this respect from that on Cub Creek, where it is found throughout the whole thickness of the 2 feet of stream gravel; on the other hand, gold from Bear and Cub creeks is light and flaky, while that from Sheridan is heavy. All the gold is bright yellow in color, assaying $19.20 to the ounce. A little "white iron" pyrite is present and also an abundance of black sand, which is entirely removed by the magnet.[b]

From 1903 to 1907 a little desultory prospecting and mining was done, but during the latter year the building of a ditch along the west slope of the valley revived interest in the region. The small precipitation of 1908, however, prevented any extensive use of the new ditch, and in 1909 there was no evidence that productive mining was in progress.

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[a] Moffit, F. H., The Fairhaven gold placers, Seward Peninsula, Alaska: Bull. U. S. Geol. Survey No. 247, 1905, p. 64.

[b] Moffit, F. H., op. cit., p. 64.

In spite of the small production of gold, this region is of interest as indictaing that the placer has been derived from the ancient lavas that form the Buckland and Kewalik divide. It will be remembered that this source of origin was suggested as a possibility for the placers on Alameda Creek in the Koyuk basin, which is on the southern extension of this lava series. It should be pointed out, however, that although a little local mineralization may have affected this group of rocks here and there, so far as can be foretold by present indications, there is slight chance of finding any considerable extent of rich placer on those streams where the ancient lavas form the country rock. In other words, it is believed that only "one man camps" will be established on streams deriving their gravels from areas of ancient lavas.

KIWALIK RIVER BASIN.

The main production of Kiwalik River comes from Candle Creek and its tributaries. As the larger part of this stream lies outside of the area represented on the map accompanying this report and as the region was not visited in 1909 by the geologists of the Survey party it is desirable to omit any detailed description of the placers. As complete descriptions as the facts in hand warranted have already been published by the Survey.[a] From these reports it will be learned that the production from Candle Creek, on which gold was discovered in 1901, has amounted to about $2,500,000 in gold. During the first years of the camp most of the values came from the creek gravels, but afterward high-level deposits were found which seem to be of a type intermediate petween bench and hillside placers. As these deposits are in places deep, mining has been carried on in winter as well as in summer. According to Moffit:[b]

> The gold is usually flattened and black so that when cleaning out the boxes miners are often seen biting a nugget to make sure that it is gold and not one of the iron stones. Quartz is at times embedded in the larger nuggets and gold is observed now and then in the form of fine veinlets through the iron stones. One nugget weighing $62.10 and a second weighing $36 have been taken from the creek.
>
> Black sand is unknown in the clean ups; pyrite and a few small pieces of rutile which occasionally have been mistaken by the miners for tin ore are the heavy minerals associated with the gold; it is not considered a favorable sign when the iron stones fail.

So far as is known all of the material in the Candle Creek placers is of local origin, although the source of the gold in bed rock has not been determined.

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[a] Moffit, F. H., The Fairhaven gold placers, Seward Peninsula, Alaska: Bull. U. S. Geol. Survey No. 247, 1905.

Henshaw, F. F., Mining in the Fairhaven precinct: Bull U. S. Geol. Survey No. 379, 1909, pp. 364–369.

[b] Moffit, F. H., op. cit., p. 62.

During the early development of this region considerable difficulty was experienced owing to the lack of a sufficient supply of water for mining. This deficiency was met in part by the construction of short ditches within the Candle Creek basin, but as the supply was still inadequate a ditch over 33 miles in length was built in 1907 along the west band of Kiwalik River from the mouth of Glacier Creek to the mouth of Candle Creek. This ditch has a capacity of 20 to 30 second-feet and the height of the lower end above Kiwalik River at that point is about 250 feet. Henshaw[a] in the report already mentioned suggests that the most practical method of obtaining a larger water supply is by pumping from Kiwalik River. Power for such an enterprise might be derived either by using Chicago Creek coal as fuel or by the transformation of water power below Imuruk Lake into electricity.

SUMMARY.

From the distribution of the areas where placers of economic importance have been mined certain facts of value in assisting further prospecting may be learned. Some of the more evident conclusions are as follows: The Cretaceous areas are not promising placer regions and neither are those places promising that derive their deposits mainly from Cretaceous rocks, as, for instance, the marine deposits on the east shore of Norton Bay; no placers of other than distinctly local importance occur in regions deriving their gravels from the pre-Cretaceous igneous rocks; no placers at all have been found in the gravels derived solely from the recent effusive rocks; no gravel deposits derived entirely from the limestones of Paleozoic age contain gold in workable quantities; local placers may occur near the post-Cretaceous intrusions; the most extensive placers occur in the areas of metamorphic sedimentary schists, especially near their contact with the heavy limestones; gold placers are usually found where concentration of gravel derived from the Paleozoic black quartzite has occurred. These general conditions are modified by local conditions; thus in places where concentration has been strong richer deposits are to be expected than in places where less sorting has occurred. From this fact it follows that the glaciated areas hold less promise of placer deposits than the unglaciated areas.

LODE PROSPECTS.

Although, as has been shown, placer gold has been found on many of the streams in the area of metamorphic rocks, no veins sufficiently rich to allow lode mining have been discovered. This is probably in part due to the absence of adequate prospecting. Quartz veins containing gold have been found at many places and at a few places pits have been sunk; copper sulphides have also been found; and silver-bearing galena has been known almost since the first white men visited the region.

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[a] Henshaw, F. F., op. cit., p. 368.

GOLD LODE PROSPECTS.

In order to give an idea of the places where auriferous veins have been exploited the following notes may be of service.

A sample taken from the schists adjacent to some quartz stringers near the mouth of Ophir Creek contained gold in such quantities that when crushed in a hand mortar and panned free gold was obtained. On Crooked Creek, a tributary of Ophir Creek, there " is a mineralized belt 12 feet wide which strikes northwest. In this impregnated zone vein quartz is associated with pyrite. It is reported to assay as high as $8 to the ton." [a] Near this place, on the divide between Goldbottom and Crooked creeks, is a gold-bearing vein which seems to be a continuation of this lead. Mineralization on a small scale has been recognized at several places on Goldbottom and Warm creeks, and a short distance from the mouth of Warm Creek a vein, on which some development work had been done, was found at the contact of schist and limestone. " Near the mouth of the creek [Warm Creek] are two quartz veins, one about 3 feet wide and the other about 1 foot wide, striking N. 30° E." [b]

No productive lodes have so far been found in the Bluff region. Brooks says: [c]

> So far as observed, the schists appear to be mineralized only near their contacts with the limestones. At these places quartz veins cutting the foliation of the schists are not uncommon. The individual veins appear to be of small extent, but at some localities a stockwork forms a considerable mass of low-grade ore. The ores appear to be chiefly iron pyrite with some chalcopyrite and arsenopyrite. * * *
>
> An impregnated zone is well exposed along the sea cliff about three-fourths of a mile east of the mouth of Daniels Creek. * * * At this locality a belt of mica schist about 60 feet wide is more or less impregnated by pyrite-bearing quartz stringers. The belt, including some irregular limestone masses, is bounded by graphitic limestone walls which dip away from the schists and form a small anticline much broken by faults. * * * At the west contact a band of schist 20 feet in cross section lies between one of the included limestone masses and the country rock. In this band the mineralization is more intense than in the rest of the schist. Here a series of gash veins, the largest of which is 18 inches in width, cut the foliation of the schist. [See fig. 15.] A mass of crushed material or gouge forms the hanging wall of this deposit and along this zone, which has been a plane of movement, the quartz veins are cut off abruptly. Stringers of quartz do, however, occur in the limestone on both sides of the schist. The ore appears to be chiefly iron pyrite and mispickel, with some chalcopyrite; the gangue is mostly quartz, with some calcite.

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[a] Collier, A. J., and others, op. cit., p. 252.

[b] Idem, p. 255.

[c] Brooks, A. H., op. cit., pp. 285-292.

Although this mineralized zone was known for several years not much active exploitation was undertaken until 1907. At one claim a shaft 50 feet deep was sunk and a short drift about 15 feet in length was turned off. On the adjoining claim the zone of mineralization is so wide that two shafts, one on the hanging wall and one on the foot wall, have been sunk. One of these is reported to be 100 feet deep; the other is slightly less than half that depth. On the next claim, also, two shafts have been sunk to a depth of approximately 50 feet. Two shorter shafts have been put down on the next claim, and one shaft about 75 feet deep has been sunk near the end line of the next claim beyond. In 1907 the ore from these properties was crushed in an arrastra which was operated by a horse; it was intended to erect a stamp mill later. The developments at this place, however, have not been ascertained for the last two years.

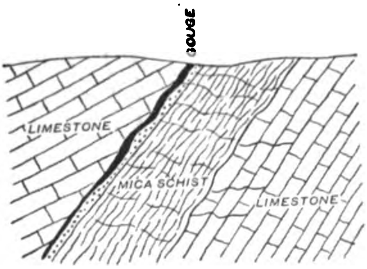

FIGURE 15.—Diagrammatic section of impregnated zones, Bluff region.

According to Brooks, in 1906 a lode 3 miles east of Bluff had been developed to some extent.[a] It was located near the shore, and was said to be 14 feet wide and to yield as much as $30 in gold to the ton. The ore is reported to be iron pyrite and mispickel. A few tons have been sacked and prepared for shipment but practically nothing is known about the mode of occurrence.

A small amount of prospecting has been done near the head of Walla Walla Creek somewhat east of the contact of the igneous rocks and the black quartzitic slates. Although rich specimens are said to have been found here, a careful examination of the rock on the dump failed to disclose enough mineralization to encourage further prospecting. A small amount of limonite staining the joints and fracture planes of the rocks was observed, but there is no vein or distinct lead. Developments at this place consist of an open cut about 25 feet long and a crosscut adit, started about 500 feet away and down the hillside, which has gone in 38 paces (about 100 feet), all the way through barren rock. An analysis of rock from this open cut by Peter Esch, of Nome, gave a trace of gold.

As placer gold is derived from veins, it is certain that auriferous veins must occur widely throughout the area. Whether such veins can be economically mined is a question which can be decided only by more active development. It is probable that if auriferous veins are exploited in the future the mining problems involved will fall within commercial rather than geologic boundaries.

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[a] Brooks, A. H., op. cit., p. 292.

SILVER-LEAD DEPOSIT.

Within the area of metamorphic rocks of southeastern Seward Peninsula one deposit of argentiferous galena has been of some economic value. This lode, staked in 1881, was probably the second one discovered in the entire territory of Alaska. Although the claims were not recorded until July, 1881, galena had been known for a year or more before, and Petrof, in the census report for 1880, mentions that silver-lead ore had been found in the vicinity of Golofnin Bay. The developments at this place have been carried on at a single group of claims located on a low limestone-schist hill on the western flanks of the Darby Range. As has already been stated, the claims were located in 1881. In 1882 a company was formed which in 1883 was absorbed by the Omilak Gold and Silver Mining Company, which continued to hold the ground until 1898, when the Russian-American Mining Exploration Company took the properties. This transfer was one of name rather than of personnel. The claims were patented in 1894.

The geology in the vicinity of the mine is so complex that without more detailed study than was made in 1909 the stratigraphy is not determinable. East of the mine, toward the head of Omilak Creek, is a large area of white crystalline limestone, which, in the main, appears to dip westward at high angles. This is succeeded farther west by schistose rocks containing much biotite and quartz and some graphite. Still farther west, in the immediate neighborhood of the mine, the distribution of the various rocks is as shown in figure 6 (p. 64). Although from this map it appears that the dip is in general to the west, the evidence on the ground shows that the rocks are much deformed, and appressed folds, such as are shown in Plate XIII, *A* (p. 90), have been recognized. This fold, which pitches steeply toward the west, is shown at A on figure 6 (p. 90). It is evident that with such an amount of folding this structure is by no means so simple as appears at first sight, and even the determination of bedding is often impossible. It is believed, though it has not been definitely proved, that the schists represent younger or overlying rocks.

In addition to the dark biotite schist and the limestones there is an area of slightly sheared igneous rock similar to the greenstones of the more western part of Seward Peninsula. Although the exposures were not sufficiently clear to preclude other interpretations, it seems probable that these greenstones intrude the limestones. Owing to the amount of deformation and consequent metamorphism it is probable that some of the greenstones are included in the areas mapped as schist. The fact that the greenstone is more easily recognizable in the midst of the limestone may be due to the protection given it by that rock, which is more easily deformed than the schist, whose resistance to dynamic metamorphism is more nearly equal to that of the igneous rocks.

According to Mendenhall the ore occurs near the contact of this intrusive and the limestone.[a] From the study of the region in 1909 this conclusion could not be verified as the shaft was inaccessible and the only mineralization seen was in the midst of the limestone. In the absence, however, of ore-bearing minerals in the greenstone it seems doubtful whether the galena could have been introduced at the time of the intrusion. Furthermore, the well crystallized character of the ore suggests that its deposition was later than the deformation of the region, whereas the greenstone was earlier.

Two kinds of ore minerals are found in this deposit—argentiferous galena and stibnite. So far no interrelation between the two has been shown, but it is believed that both were introduced at essentially the same time. It should be noted that the deposits containing the galena seem to be topographically above those with stibnite.

From the reports of others—as it was not possible to see the underground workings personally—it was learned that "no continuous vein of galena ore existed, the ore being found only in irregular and disconnected pockets."[b] None of the pockets were of large size and the better ones occurred entirely within the limestone. Some of the ore was thickly covered with products of oxidation, mostly lead carbonate.

About 400 paces south of the galena shaft there are a shaft and an incline which were used to explore the stibnite leads. The limestone is much fractured and the ore occurs in thin streaks in the shattered zone. None of the veins seen by the writers are of sufficient size to warrant mining. The stibnite is well crystallized, the thicker stringers apparently occupying fault planes and sending small offshoots into the limestone, which, near the ore, is abnormally granular and sugary.

Considering the number of years the ground has been held and the large expenditures incurred, the amount of development work is astonishingly small. A shaft 180 feet deep has been sunk near the eastern margin of the limestone on top of the hill, and two short drifts have been turned off in the search for ore pockets. The upper part of the shaft is in limestone, but the lower is in schist, as the contact dips toward the west. The shaft is well timbered and is fairly dry. Hoisting is done by power, a bucket not running on guides being used. Electric lights are used around the shaft house and underground. Two outfits for drilling have been used, one an air compressor and air drills and the other an electric drill plant. Electricity for these uses is furnished by a coal-oil engine located near the main bunk house on Omilak Creek.

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[a] Mendenhall, W. C., op. cit., p. 214.

[b] Idem, pp. 213–214.

At 200 to 300 feet, vertically, above Omilak Creek an adit has been started to intersect the shaft in depth and thus obviate the necessity of hoisting the rock to the top of the hill and then taking it down again for shipment. The length of the adit is 187 paces, or, approximately, 500 feet; this distance was in massive white limestone somewhat shattered, but nowhere showing mineralization.

In addition to the equipment directly at the mine there are bunk and store houses at Cheenik, on Fish River, and also half a mile or so below the mine on Omilak Creek. At the latter place are a repair shop, electric plant, assay laboratory, electric sawmill, stable, and the other equipment usually found only at large producing mines. The company also owns a large river steamer originally built for freighting the mine supplies up the river, but it has never been used.

The production of the mine is not definitely known, but it has probably not been more than 400 nor less than 300 tons. A part of this was obtained from the various pockets below ground, but a considerable amount is understood to have come from hand picking the float found on the hillside. The following tables show the returns from assays of the ore as shipped. It should be noted that owing to the high transportation charges the ore was carefully hand picked and in some cases washed before shipping.

Returns from assays of ore as shipped from Omilak mine.

	Weight (pounds).	Gold (value per ton).	Silver (value per ton).	Lead (pounds per ton).	Lead (value per ton).	Total value per ton.
1	4,230	....	137.29	1,538	61.52	198.81
2	545	2.07	106.62	1,320	52.80	161.49
3	130,000	3.09	98.72	1,128	45.12	146.93
4	68,078	....	104.00	1,300	52.00	156.00
5	12,167	2.07	125.19	1,440	57.60	184.86
6	82,100	....	132.95	1,494	59.76	192.71
7	86,885	7.43	49.60	502	20.08	77.11
8	27,787	1.54	41.40	606	24.24	67.18
9	13,606	1.54	38.10	566	22.64	62.28
10	2,675	1.03	54.93	770	30.80	86.76
11	6,569	2.07	46.46	890	35.60	84.13
12	164	7.53	65.54	816	32.64	105.71
13	595	2.07	71.15	980	39.20	112.42
14	380	2.07	86.86	966	38.64	127.57
15	26,175	2.07	120.33	1,222	48.88	171.28

1 to 6 inclusive, solid ore from Omilak mine, tons of 2,000 lbs.; 7 to 14, inclusive, carbonate ores from Omilak mine; 15, carbonate ore concentrated by washing in sluice boxes.

Unfortunately, in these assays the data are not sufficient to determine the percentage of any of the constituents except the lead, and therefore the following assays, less complete in certain other ways, are given also:

Silver and lead in ore from Omilak mine.

	Silver (ounces per ton).	Lead (per cent).
1	173.00	75.0
2	141.00	80.7
3	158.00	78.0
4	153.70	82.0
5	162.97	78.5
6	149.16	73.0
7	142 20	74.7
8	94.30	55.9
9	60.7	10.27

Assays 1–2 by Herford Copper Works, Swansea, England; 3 by Pennsylvania Lead Company, Pittsburg, Pa.; 4–6 by W. P. Miller, San Francisco; 7 by T. Price, San Francisco; 8–9 reported by W. C. Mendenhall, op. cit., p. 214; 8 yellow carbonate ore; 9 red carbonate ore.

Assays and relative weights of part of the different ores shipped by the Omilak mine in 1889, with the price paid in open market for the same are given in the following table:

Assays and weights of ore shipped by Omilak mine in 1889.

Commercial name.	Weight (pounds).	Gold (ounces per ton).	Silver (ounces per ton).	Lead (per cent).	Price received per ton.
Red carbonate	380	0.1	92.9	48.3	$93.00
Gray carbonate	595	.1	76.1	49.0	81.00
Yellow carbonate	6.569	.1	49.7	44.5	57.00
Argentiferous galena	82,100	....	142.2	74.7	154.00

It is evident that the ore is high in silver and also usually carries a small quantity of gold. Its metallurgical treatment is simple and the ore is especially valuable to mix with other more refractory ores. The absence of fuel at a reasonable price prevents treatment near the mine and the high charges for transportation restrict shipments to ores of the higher grade.

From the foregoing descriptions certain facts are evident, which may be summarized as follows: The claims have been inadequately prospected and large expenditures have been made, apparently without disclosing a workable vein; the ore found is of excellent quality, but the quantity, so far as could be determined by the writers, is not sufficient to warrant extensive developments. The most promising area to prospect is in the limestone near its contact with the schists, but the deposits likely to be found will probably be pockets not easily adaptable to cheap mining methods and not capable of affording a large, constant amount of ore.

COPPER PROSPECTS.

Attempts have been made to develop copper leads at three places within the Nulato-Council region, but so far the results have not been encouraging, and the general absence of sulphide mineralization throughout Seward Peninsula leads one to doubt whether commercially important deposits of copper will be found. Furthermore, the necessary treatment and refining that copper must undergo before manufacture makes this metal difficult to handle in a country where high wages, high cost of supplies, and absence of transportation facilities exist. It seems likely, therefore, that until one or all of these factors are canceled or reduced, copper mining can be successfully carried on only where the deposit is exceptionally rich. No such places are at present known in Seward Peninsula.

Several shallow prospect pits were sunk in 1906–7 in the hills near Timber Creek in the Tubutulik divide, on copper-stained greenstones, near their contact with limestone. A large outfit was shipped in and extensive plans formulated, but the mineralization was not sufficient to warrant development, and after a little desultory prospecting the ground was abandoned. Specimens of the ore from this claim were assayed and, according to the owners, yielded from 17 to 70 ounces of silver to the ton and from a few cents to $1 a ton in gold as well as copper. From the high copper content reported in these assays, it is evident that the sample for assay was carefully hand-picked. From a personal examination of specimens from this ground it appeared to the writers that the copper occurred almost exclusively in the form of malachite, the green carbonate of copper, and sulphides or other original minerals were practically absent. On account of the secondary character of the ore, it is difficult to ascertain the time or mode of origin of the copper mineralization. The observed facts show that the carbonate occupies fractures and joints in the greenstone, but this does not preclude its having been derived from the leaching of copper minerals originally present in the greenstone. So far as could be determined, the copper mineralization at this place is distinctly local and in such insignificant quantity as to discourage further investigation.

On the east coast of the Darby Peninsula, about 3 miles north of Carson Creek, a little copper mineralization was observed. A small amount of exploration by means of a short, open cut had been made, but no work was in progress at the time of the visit in 1909. The copper occurs mainly in the form of the carbonate, but there is also a little chalcocite present. This ore does not occur in a vein, but seems to be a replacement of parts of the schist, so that its distribution is irregular and discontinuous. Some is also found in the joint planes, as though it had been introduced later than the deformation of the untry rock. There is a large amount of slickensiding on the rocks, showing that faulting has occurred, and it is by no means improbable that the shattering effected by these movements may have produced a more or less pervious zone, which allowed easy penetration for mineralizing solutions. The amount of mineralization is, however, slight, and there seems to be no reason for believing that a commercially workable deposit will be found at this place.

A short distance farther south is an outcrop of a nearly pure white limestone, which, though slightly sheared, is in places much brecciated. A short tunnel has been driven in on this brecciated band. Apparently some surface stains had tempted exploitation, but as the work progressed and no vein or other mineralization was found the search was abandoned. From the present condition of the tunnel and the surrounding country rock one fails to understand why mining was ever contemplated at this place.

The only other place where copper prospecting has been undertaken within the Nulato-Council region is in the Bendeleben Mountains on the divide between Kingsland and Nugget creeks. These streams are tributaries of the Niukluk from the east about 4 miles south of the Birch Creek-Niukluk divide. Prospecting in this region has been carried on for five to eight years, but no shipment of ore has been made and no considerable body has been exposed. The ore occurs near the contact of a limestone and schist in a region much faulted and intruded by small granite dikes. The ore is low grade and consists mainly of chalcopyrite, with few alteration products. No distinct vein was found, the ore occurring mainly as a replacement of the country rock in disseminated lenses and strings. A little gold is reported to be associated with the copper, but neither its value nor its relation to the copper mineralization was learned.

Although of no commercial value, the occurrence of copper sulphides in a pink granite, with rather large feldspar crystals, on the upper part of Peace River 2 or 3 miles above camp B13, is noted as giving a suggestion of the time of introduction of some of the copper mineralization. At this place there is only a little copper, but it seems to have been brought in contemporaneously with the granite. As there is no evidence at the other places already described of the age of the mineralization, this occurrence becomes significant.

From the preceding accounts of the meager amount of development work on copper lodes it is evident that no deposits of value are known. In part this may be due to lack of thorough investigation, but it is believed to be due in the main to the absence of cupriferous veins. Therefore, although valuable copper may be discovered in the future, the present conditions do not warrant search unless the enterprise is undertaken with the knowledge that the chances are against rather than in favor of success.

COAL RESOURCES.

Wherever the Cretaceous sediments are extensively developed throughout Alaska there are indications of coal. Some of these croppings in the area under discussion have been prospected and claims staked. Field examinations of some of the Alaskan coal deposits along Yukon River have been recently completed by Atwood, but the results have not yet been made available. Manuscript notes of the facts gathered by him concerning the Nulato region have, however, been furnished and have been of service in preparing the following paragraphs.

Fossils have not been found at many of the coal prospects and it is impossible to refer the various beds definitely to their proper geologic horizons. Closer correlations therefore than that the coals belong to the Upper Cretaceous will not be attempted, although it is believed that most of the deposits belong to the lower rather than the higher part of this series. One exception, in which the material is a very woody lignite, seems to be of much more recent age and is provisionally called post-Tertiary, mainly on account of its physical character.

For convenience of description a geographic order will be adopted. According to this plan, the deposits have been divided into, first, those occurring in the Yukon River drainage basin, and, second, those either in regions draining into Norton Bay or in Seward Peninsula.

YUKON BASIN.

The most eastern locality where coal has been prospected in this part of the Yukon basin is at Nahoclatilten or Louden, west of the mouth of the Melozitna. A description of these coals by Collier is as follows:[a]

> Two beds of coal were seen by the writer at this place, and two more are reported to have been uncovered in prospecting. The largest observed seam has a thickness of 1 foot. Below this seam there are about 5 feet of bony coal or coaly shale with stringers of coal. There are reported to be 3 smaller beds in the foot wall, each having a thickness of 10 inches. Owing to the apparent rather intense folding of these beds, it is impossible to place much reliance on these statements.
>
> The coal in the 1-foot seam is not crushed, although the beds are much disturbed in position. The following analysis shows it to be a bituminous coal of good quality. It is reported to have given satisfactory results in a blacksmith's forge.

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[a] Collier, A. J., The coal resources of the Yukon, Alaska: Bull. U. S. Geol. Survey No. 218, 1903, pp. 47–48.

Analysis of coal (No. 241) from 1-foot seam 5 miles above Nahoclatilten.

[Analyst, E. T. Allen, U. S. Geol. Survey.]

	Per cent.
Water	6.88
Volatile combustible matter	41.82
Fixed carbon	48.93
Ash	2.37
	100.00
Sulphur	.65
Fuel ratio	1.17

Coke slightly coherent.

These coal beds have been known for several years, and various attempts have been made to open here coal beds of commercial importance, but thus far no seams thicker than 12 inches have been found.

No other coal prospects have been noted lower down on the Yukon until about midway between the mouth of the Koyukuk and Nulato. A mine, called from its owner the Pickart mine, was noted by Schrader in 1899; it is therefore one of the oldest coal mines in Alaska. According to Collier:[a]

> At the Pickart mine one coal seam has been exploited which strikes N. 75° E. and dips 35° N. Two rolls, or horsebacks, are reported to occur in the floor of the coal bed. Whether these are in the nature of faults due to movement of strata along the coal bed or irregularities in deposition of the sediments constituting the floor the writer was unable to determine. Near these rolls the coal shows considerable crushing, which suggests that the roll is formed by deformation. The Pickart coal bed has a thickness of 30 inches at a distance of 300 feet from the entrance to the mine, but near one of the rolls above referred to the seam measured only 18 inches. Mr. W. E. Williams, manager of the Pickart mine, reports that in mining this coal a roll was encountered in the workings above the coal mine gangway in which the floor of the bed was raised up, pinching the coal down to a knife-edge thickness. The roll extended in a nearly straight line and approached the gangway at a rate of about 1 foot in 20. On cutting through this roll good coal was found.

Analyses of the coal from near this mine published by Collier are as follows:[b]

Analyses of semibituminous coking coal on the Yukon.

[No. 1 from 12 miles above Nulato, on the Yukon; analyst, George Steiger, U. S. Geol. Survey. Nos. 2 and 3 from Pickart mine, on the Yukon; analyst, E. T. Allen, U. S. Geol. Survey.]

	1.	2.	3.
Moisture	0.86	1.02	1.64
Volatile matter	25.75	27.33	24.98
Fixed carbon	66.51	65.03	58.18
Ash	6.88	6.62	15.20
Sulphur	....	.56	....
Fuel ratio	2.22	2.37	2.32

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[a] Collier, A. J., op. cit., p. 50.

[b] Idem, p. 62.

In 1907 this mine was visited by Atwood, who reports that no work had been in progress for several years. According to him there are at least four thin seams of coal stratigraphically higher than the one the mine was opened on. These upper beds are only from 6 to 8 inches in thickness, and are associated with carbonaceous shales, which show frequent signs of cross-bedding and ripple marks.

About a mile above Nulato, Collier noted a prospect hole sunk in the sandstones called Nulato sandstone by Dall. The section exposed showed 2½ feet of bony coal with several bands of clay. One 6-inch bed of clean coal was uncovered and, it is reported, was used to some extent for blacksmithing at Nulato. There has been no recent work at this prospect, and it is evident that the seam is too thin to invite further investigation.

Four miles below Nulato, in the name sandstone in which the other prospects already described occur, is a coal bed that has been opened to a small extent. This mine is locally known as the Busch mine. No mining has been done here for several years. Atwood, when he visited the prospect in 1907, reported that the slope had caved so as to make the mine inaccessible. According to Collier, at the time of his visit in 1903:

> In the tunnel, which extends about 40 feet, large bodies of crushed coal 4 to 5 feet in thickness are exposed. The coal is regarded as bituminous, having a fuel ratio of 1.76 and a water content of 11.17 per cent. The high percentage of water is probably due to decomposition of the coal in the croppings. No coal has been produced.[a]

Aanalysis of coal from Busch mine, 4 miles below Nulato.[b]

[Analyst, E. T. Allen, U. S. Geol. Survey.]

Moisture	11.17
Volatile matter	29.48
Fixed carbon	52.02
Ash	7.33
	100.00
Sulphur	.44
Fuel ratio	1.76

Coke, noncoherent.

About 5 miles below the Busch prospect is the Blatchford mine, which is also abandoned. Collier reports:[a]

> One workable coal bed has been opened at this place. This bed has been crushed and sheared by the movements of the inclosing strata, making it very irregular. Large masses 8 feet in diameter have been found and mined out, showing that before it was disturbed the coal bed probably had considerable thickness. The coal has a tendency to break up into fine pieces, though it is

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[a] Collier, A. J., Bull. U. S. Geol. Survey No. 213, 1903, p. 281.

[b] Collier, A. J., The coal resources of the Yukon: Bull. U. S. Geol. Survey No. 218, 1903, p. 53.

> a bituminous coal having a fuel ratio of 3.30, the highest of any coal on the Yukon, and a water content of 1.36 per cent. The ash is only 2.22 per cent, making it, by approximate analysis, the best coal seen by the writer on the Yukon River.
>
> This mine has no visible development or permanent equipment. The workings lie below the level of the river and the entrance is covered with water during the summer months, so that it can be worked only in the winter after the freezing of the river, where the ice filling the upper workings must be mined out before the coal can be reached. The mine has probably produced about 300 tons of coal.

The Williams coal mine is located on the west side of the Yukon just south of the mapped area. It has been more extensively developed than any of the mines already described, but as it does not come within the area covered by this report, description will be omitted except to state that in a broad way conditions are the same there as in the other prospects.

NORTON BAY BASIN AND SOUTHEASTERN SEWARD PENINSULA.

Coal has been reported at a number of places along the eastern shore of Norton Bay, but so far as known no beds of a sufficient size to allow profitable mining have been discovered. Dall mentions a 2-foot bed of shale and lignite, possibly Kenai in age, on Ulukuk River, a tributary of the Unalaklik from the north.[a] It was reported to have no commercial value. Brooks[b] states:

> Capt. D. H. Jarvis informed the writer that some very good-looking coal had been found near Unalaklik Cape near the eastern shore of Norton Sound. These [beds] probably belong to the same series described by Dall.

Several openings have been made near the mouth of the Koyuk on the western side close to camp B17. Unfortunately the shafts were not in condition to be examined, and the only information gained was from a study of the material on the dump, as there are no exposures of the coal-bearing rocks in the neighborhood. Although lignitic material was found at this place, several years of desultory prospecting have failed to disclose a workable bed. The shafts show a series of sandstones and clays which have weathered badly on the dump and appear much less consolidated than the average sandstones near Nulato. It is understood that during 1909 the company formerly interested in this claim abandoned the enterprise.

In this same region coal float has been found on Coal Creek and claims have been recorded, but none of them was being prospected in 1909. Probably little of value was found as the series is without doubt similar to that near camp B17.

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[a] Dall, W. H., Correlation papers, Neocene: Bull. U. S. Geol. Survey No. 84, 1892, p. 246.

[b] Brooks, A. H., Coal resources of Alaska: Twenty-second Ann. Rept. U. S. Geol. Survey, 1902, pt. 3, p. 560.

Mendenhall[a] says concerning his investigation in southeastern Seward Peninsula:

> The only rocks encountered in the reconnaissance likely to carry coal are the sediments supposed to be of Tertiary age outcropping on the Tubutulik and Koyuk rivers in narrow belts. No direct evidence of the presence of this mineral was secured on the Koyuk, but along the river bank associated with the sandstone outcrops on the Tubutulik are numbers of small pieces of bright compact coal seemingly of good quality.

The presence of this coal float has long been known to prospectors but so far no beds that would warrant investigation have been discovered.

As previously stated one locality was visited in 1909 where there is a woody lignite of relatively recent age and differing from those previously described. This exposure is on the Rathlatulik, a tributary of Fish River, about 10 miles above the junction of the streams.

A shallow pit has been sunk here and slightly carbonized fragments of wood found. Underneath this layer of woody material is a blackish-green calcareous muck which is nearly flat or has a slight slope toward the east. A cross section of the valley at this point shows a low bench about 5 feet above the water, succeeded on the east by another bench 15 feet higher 100 paces beyond the stream and separated from the lower bench by a steep cliff. All the material from the stream to the top of the 15-foot cliff is well-rounded gravel. Several abandoned river beds are found on the lower bench.

The coal is not over 18 inches thick and is of poor quality, having advanced little beyond the wood stage. Resin is abundant in many of the samples of this material. No tests of the coal were made, but from its physical character it does not seem possible that it could be used for fuel except very locally. No accurate estimate of the amount of material available could be made without further exploitation, but it is believed to be of very slight extent and not of sufficient value to warrant further development.

CONCLUSIONS REGARDING THE COAL RESOURCES.

In the foregoing paragraphs the places where the coal-bearing rocks have been prospected to some extent have been described with the object of showing the general character of the known coal deposits. Indications of coal have been noted at many other places, but the types are essentially similar and do not merit specific description. There are certain conclusions that may be drawn from the facts that may save prospectors from spending their time unprofitably in the search of coal. Coal will be found only in the areas of Cretaceous sediments. No economically important beds are to be expected in the unconsolidated alluviums such as those in the Fish River basin on the Rathlatulik. From the fact that so far there is no productive mining on any of the coal-bearing rocks outcropping along the Yukon within the mapped area, it seems improbable that workable beds in the same series of rocks will be developed in the immediate future in the more remote regions where transportation facilities and markets are wanting. Although thicker beds may be found here and there, the additional cost of transportation for each mile that the deposit lies back from the river or from some other cheap avenue of communication increases much more rapidly than the thickness of the bed could be reasonably assumed to increase. It is improbable, therefore, that workable coal, where it is not now known, will be found in the Nulato-Council area.

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[a] Mendenhall, W. C., A reconnaissance in the Norton Bay region, Alaska, in 1900, a special publication of the U. S. Geol. Survey, 1901, p. 214.

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 450

MINERAL RESOURCES
OF THE
LLANO-BURNET REGION, TEXAS
WITH
AN ACCOUNT OF THE PRE-CAMBRIAN GEOLOGY

BY

SIDNEY PAIGE

WASHINGTON
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1911

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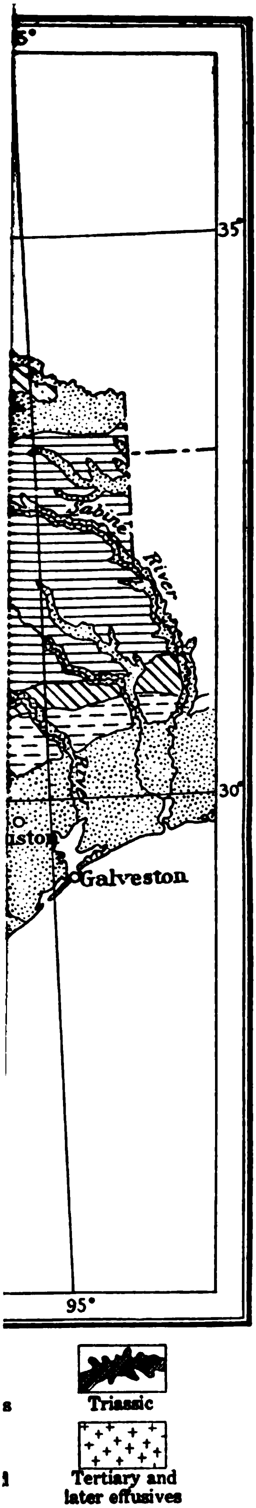
5°
35°
30°
95°
Sabine River
River
uston
Galveston
Triassic
Tertiary and later effusives

MINERAL RESOURCES OF THE LLANO-BURNET REGION, TEXAS, WITH AN ACCOUNT OF THE PRE-CAMBRIAN GEOLOGY.

By Sidney Paige.

INTRODUCTION.

The field work on which the following report is based was begun in the summer of 1908 under the direction of A. C. Spencer, who was assisted by the writer, and was completed in the fall of 1909 under the direction of the writer, who was assisted by Fred H. Kay. A. C. Spencer and W. S. Bayley cooperated in the field work, and Mr. Spencer has contributed descriptions of certain of the iron-ore deposits. Howland Bancroft also spent a short time in the field. A general report on the Llano and Burnet quadrangles, to be published in folio form, is now in preparation.[a] The present report deals chiefly with the geologic relations of the pre-Cambrian rocks and the associated iron ores. The stratigraphic and structural relations of the Paleozoic and Cretaceous rocks are only briefly treated, but will be discussed more fully in the later report.[a]

The writer wishes to express his indebtedness to Dr. Spencer, whose acquaintance with pre-Cambrian structure and iron ores has been of great value in both the field and the office work. Thanks are due also to Prof. W. S. Bayley for counsel and suggestion, and to Mr. N. J. Badu, of Llano, whose knowledge of Llano County was of great assistance during the field work.

The central Texas region lies in the broad regional coastward slope, of which Texas forms a part and which constitutes a great geologic province reaching from the Cordilleras to the Gulf of Mexico. (See Pl. I.) In this region, about midway between the Cordilleras and the Gulf the peculiar condition exists that erosion has exposed rocks of pre-Cambrian and Paleozoic ages within and about the rim of an oval structural and topographic basin which is nearly surrounded by Cretaceous rocks on its outer border. This area of old rocks is largely included in the Llano and Burnet quadrangles. (See Pl. II.)

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[a] Paige, Sidney, Llano-Burnet folio, Geol. Atlas U. S., U. S. Geol. Survey. (In preparation.)

As the principal mineral resources of the region are confined largely to the Llano quadrangle, this report deals almost entirely with that area.

The Llano quadrangle includes portions of Llano, Mason, and San Saba Counties in central Texas. (See Pl. III, in pocket.) It is bounded by parallels 30° 30′ and 31° and meridians 98° 30′ and 99° west, and covers 1,024 square miles. The region is accessible by the Houston & Texas Central Railroad, which terminates at Llano, the county seat of Llano County. This road connects at Lampasas, about 20 miles north of Burnet, Burnet County, with the Gulf, Colorado, & Santa Fe Railway. Llano is the principal town of the quadrangle.

TOPOGRAPHY.

A casual observer, standing on an eminence, such as Town Mountain, near Llano, will be impressed with the basin-like form of the broad valley of Llano River. From such an eminence a broad rolling plain may be seen stretching east, west, north, and south to the horizon, which is marked by an encircling scarp of Paleozoic rocks. Within this broad area, however, there are many minor irregularities. These irregularities are of two types—first, mountain-like masses, such as Riley, Packsaddle, Putnam, House, and Smoothingiron Mountains; and second, smaller masses, such as the group of hills west of Oxford and that northeast of Babyhead, as well as the many isolated hills north and south of Llano. The masses of the first type are characterized by cappings of nearly horizontal beds and steep marginal scarps, and present to the observer mesa-like outlines; those of the second type are maturely dissected hills and isolated cones that rise rather abruptly from the surrounding plains. The form of the masses of both types depends on the nature of the rocks composing them. Encircling the pre-Cambrian basin described above is a plateau of Paleozoic and Cretaceous rocks, more or less maturely dissected.[a]

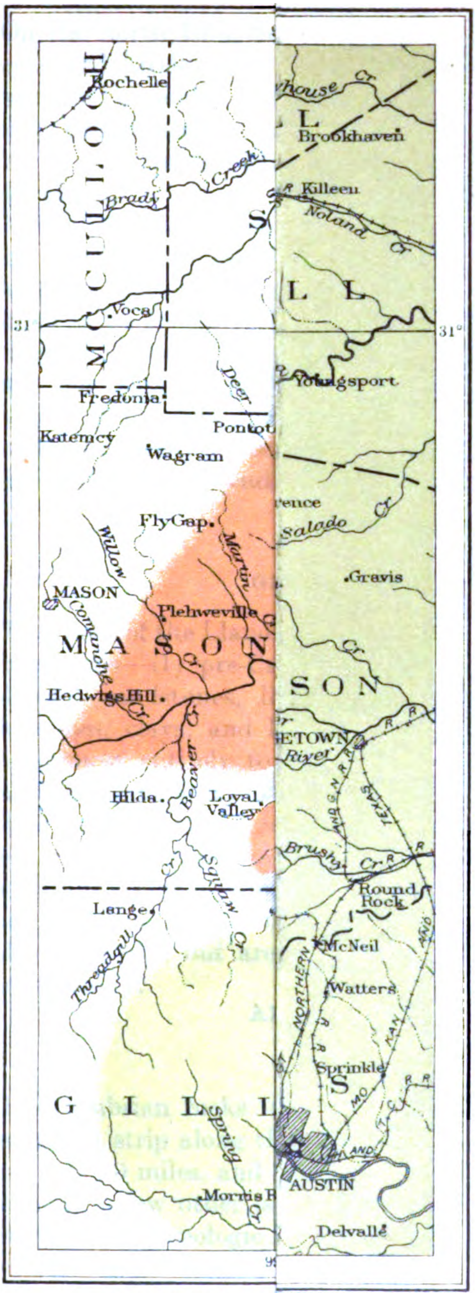
The northern border of the Llano quadrangle lies within the Paleozoic plateau; its western part is a rolling plain, which to the east and approaching Colorado River becomes more broken and irregular. The Paleozoic scarp to the west and south does not lie within the Llano quadrangle.

DRAINAGE.

The region included in the Llano quadrangle is drained almost entirely by Llano River and its northward and southward flowing tributaries. The quadrangle is nearly halved by Llano River, which flows eastward across it and enters Colorado River at Kingsland, in the Burnet quadrangle.

---

[a] For a detailed classification of Texas plateaus see Hill, R. T., Physical geography of the Texas region: Top. Atlas U.S., folio 3, U. S. Geol. Survey, 1900; Geography and geology of the Black and Grand prairies, Texas: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901.



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GENERAL EXAS

ogy within Llano and Burnet quadrangles by
Spencer, Sidney Paige, W. S. Bayley, and
H. Kay. Dotted boundaries compiled from
by Robert T. Hill

LEGEND

SEDIMENTARY ROCKS

☐ Cretaceous

☐ Paleozoic

METAMORPHIC AND IGNEOUS ROCKS

■ Algonkian (?)

Note: *Dotted boundaries are only approximate West of meridian 99° they can not be placed on the map*

⚒ Quarry

× Mine and prospect

1. Barringer Hill
1a. Fergusonite and gadolinite
1b. Gadolinite in pegmatite
1c. Allanite and fluorite
2. Magnetite
2a. Iron Mountain prospect
2b. Olive mine
3. Heath gold prospect
4. Graphite prospect
5. Serpentine and talc
6. Talc
7. Lead-galena
8. Pyrite bodies

On the north, Elm, San Fernando, Johnson, Pecan, and Mitchell Creeks and Little Llano River are the important affluents of Llano River; on the south, Hickory, Bullhead, Sixmile, Flag, Oatman, and Honey Creeks are the large streams. Sandy Creek, in the southern part of the quadrangle, an exception, flows eastward into the Colorado.

Nearly all the streams of the region within the pre-Cambrian basin carry a great and increasing burden of sand. During most of the year their beds are apparently dry, and it is only by digging that water can be found. Llano and Little Llano Rivers and a few other spring-fed streams are exceptions. The infrequent but torrential rains, the stripping of the granite areas of vegetation by the overstocking of ranches, the alternation of intense heat by day and of coolness by night, which tends to disintegrate the rocks, all combine to bring about this condition of the streams.

GEOLOGY.

GENERAL FEATURES.

The rocks of the Llano-Burnet region fall naturally into three broad subdivisions—(1) pre-Cambrian schists, gneisses, and granites; (2) Paleozoic sandstones, limestones, and shales; and (3) Cretaceous sandstones, clays, and limestones. The Cretaceous rocks are confined almost entirely to the Burnet quadrangle, and appear in the Llano quadrangle in but one small area.

The Paleozoic strata, which completely surround the pre-Cambrian area, are more or less folded and faulted, and are separated from the pre-Cambrian by an unconformity representing a great time interval. The Cretaceous formations rest in almost undisturbed position on the Paleozoic rocks, but are separated from them by a great erosional unconformity.

ALGONKIAN (?) ROCKS.

GEOLOGIC UNITS.

Pre-Cambrian rocks underlie the larger part of the Llano quadrangle. A strip along the northern edge, however, ranging in width from 3 to 10 miles, and Riley and Cedar Mountains, Putnam Mountain, and a few other isolated areas are covered by Paleozoic sediments. In the geologic mapping of the area (see Pl. III) four major divisions of pre-Cambrian rocks have been discriminated, namely, (1) the Packsaddle schist, a series predominantly of basic type, including amphibolite and mica schists and old basic intrusive rocks; (2) the Valley Spring gneiss, a schist-gneiss series, including quartzites or their derivatives, light-colored mica schists, and acidic gneisses; (3) a very coarse grained pink granite, which could not be separately mapped over the area; (4) all the remaining granitic rocks, including a number of varieties. All these rocks are believed to be of Algonkian(?) age. In addition to these major distinctions, bands of crystalline limestone and wollastonite were mapped wherever possible. Likewise the outcrops of a quartz porphyry of peculiar type, locally termed opaline granite, have been indicated, and a serpentine mass near Oxford has been shown. Iron-ore prospects and some lean banded ores are also represented. The area surrounding the Llano-Burnet region is shown on a general map (Pl. II), on which the several economic resources are indicated.

A glance at the map forming Plate III (in pocket) will show clearly in a general way the northwest-southeast trend of the schist-gneiss series; also the complicated and irregular distribution of the granitic intrusive rocks.

GRANITES.

GEOLOGIC RELATIONS.

The granite in this area is invariably intrusive and is almost omnipresent. It cuts the schist series in large and small masses, in dikes, in sills, and, if pegmatite may be considered a phase of granite, it is found both in minute veinlets and in huge dikes and sheets. The area contains rock of every grade between pure granite and pure schist. Certain localities are characterized by pure granite masses of batholithic type, such as the area of coarse granite in the southwestern portion of the quadrangle, the area immediately west of Cedar Mountain, and the area east of Lone Grove. Other areas show an intimate mixture of granite and schist, the schist being literally the sponge which has soaked up and become permeated with granitic material. Such permeation is best developed about the edges of the large granitic masses, though not at all confined to those bodies. (See Pl. V, *B*, p. 76.)

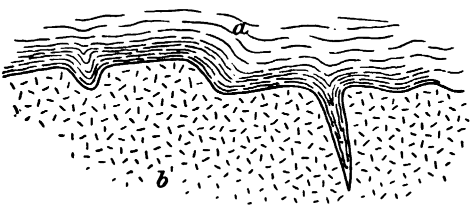
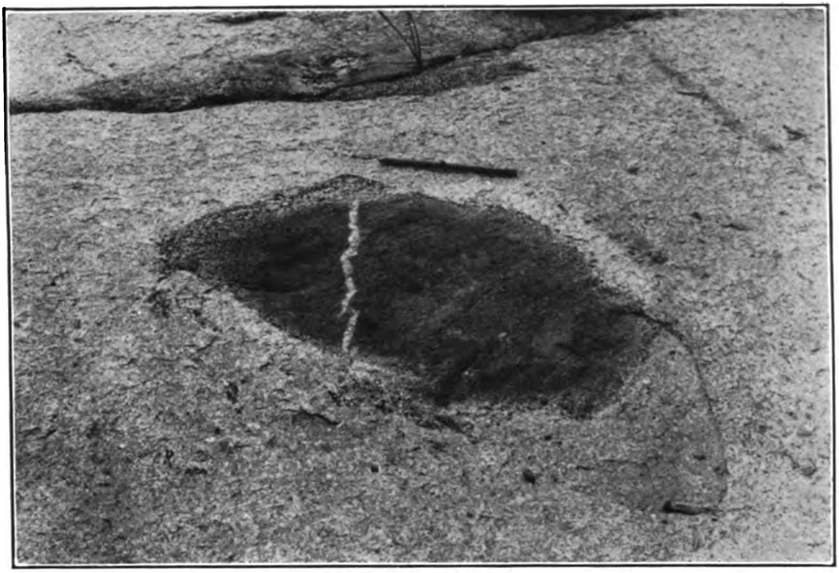


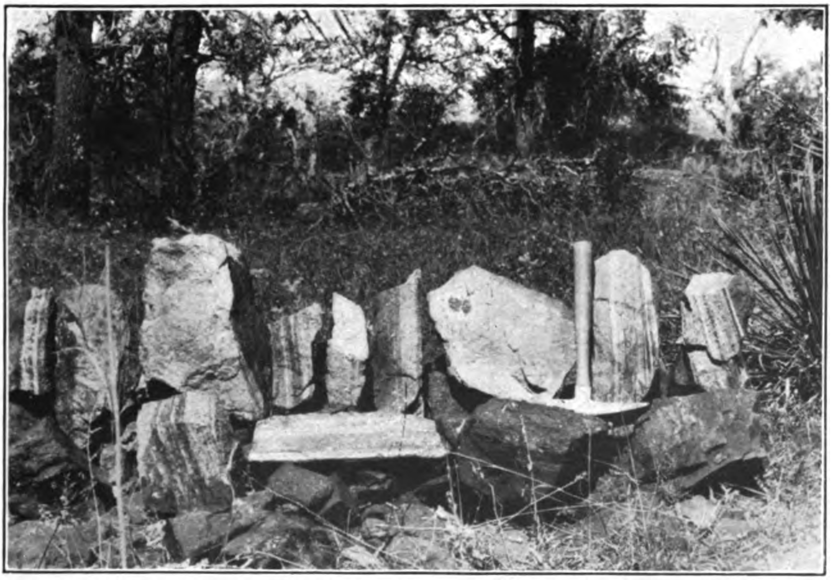
FIGURE 1.—Local flowage of schist at granite contact. *a*, Schist; *b*, granite.

The manner in which intrusion was effected varied. In some places portions of the schists were in a plastic state and flowed under the influence of pressure (see fig. 1); at other localities the contacts of the cutting dikes are sharp, indicating a condition of considerable rigidity; elsewhere the temperature of the intruding mass was so high that masses of the schist lost their identity and passed by gradual melting into solution (see Pl. IV, *A;* also fig. 18, p. 62); and elsewhere, again, granitic material, following planes of least resistance, forced 'f between the layers of the schists and formed injection gneisses.



A. ASSIMILATION OF SCHIST FRAGMENT ALONG BORDERS AT CONTACT WITH GRANITE.

See page 10.



B. BANDING OF MAGNETITE ORE.

See page 58.

The results of the processes outlined above may be seen both on a small and on a huge scale, and afford a fine example of the conditions existing about the borders of a great batholithic mass that lies in contact with a deeply buried sedimentary series.

The dikes, sills, and broader masses of pegmatite, which occur in great abundance and in all sizes, are worthy of special mention, particularly the broader masses, which are locally developed at contacts of schist with crosscutting granite dikes. In the areas about Hog Mountain such sheets are finely developed, and it is believed that they indicate the proximity of schists now removed by erosion.

TYPES AND DISTRIBUTION.

Three types of granite have been distinguished on the geologic map—(1) a very coarse grained homogeneous rock; (2) a medium to fine grained granite, including some coarse-grained varieties; and (3) an opaline quartz-feldspar porphyry. Microscopic examination has shown that the distinction is largely textural, the mineralogical constituents in the three types being essentially the same.

The coarse-grained granite has been mapped in two areas—one in the southwest corner of the quadrangle, a large subcircular area with Prairie Mountain as a center; the other farther north, in the vicinity of Smoothingiron Mountain. Granite of the same type occurs east and southeast of Lone Grove and in other localities, but in areas so small that it could not be consistently differentiated in mapping. Conclusive evidence in regard to the relative age of this coarse granite was not discovered, but tentatively it may be considered intrusive in the finer-grained granites.

The granite of the second type, the widespread dominant rock of the region, includes various textural types, ranging in texture from very coarse to very fine grained, but has been mapped as a unit.

The granitic rock of the third type, the opaline quartz-feldspar porphyry, invariably occurs as a dike rock cutting both the schists and the intrusive granites which accompany them. Its outcrop may be followed, with interruptions, from a point about 3¼ miles east of Llano, on the Llano-Lone Grove road, northward through Miller Mountain for 6½ miles, where it bends to the northeast and forms a hook passing around the town of Babyhead and ending about a mile southwest of that place.

PETROGRAPHY.

COARSE-GRAINED TYPE.

The very coarse grained granite is of reddish tone, due to the large, finely developed potash feldspars, the largest an inch long and three-fourths of an inch broad, the average length being perhaps half an inch. The space between these well-crystallized, finely developed crystals is filled with quartz. Biotite, the dominant ferromagnesian mineral, is well developed in stout columns and rather abundant. Locally a parallel arrangement of the large feldspars was noted in the vicinity of Bullhead Mountain, a phenomenon probably due to movement under pressure while the magma was yet in a more or less viscous state.

A microscopic examination shows the following characteristics:

Very coarse granite from Watch Mountain, near Walnut Springs: Feldspars are microcline, orthoclase, and albite-oligoclase. Microcline dominant. Length one-half inch to 1 inch or more, width one-fourth to one-half inch. Quartz filling space between feldspars. Biotite mica abundant in stout columns one-eighth inch or more in length. Perthitic intergrowth of microcline and albite noted.

MEDIUM TO FINE GRAINED TYPES, INCLUDING SOME COARSE VARIETIES.

The granites mapped under this head include many varieties, from fine to coarse grain, but are, in general, chemically and mineralogically similar. Differences of texture and variations in the quantity of the ferromagnesian minerals account for most of the varieties.

An examination of numerous specimens reveals an abundance of microcline, with orthoclase, albite-oligoclase, biotite, quartz, and hornblende. The granites are distinctly potash rocks, though they almost invariably contain soda. They also contain the usual accessory minerals—magnetite, apatite, titanite, etc. Several hornblende granites were noted, but their areal extent is small.

Petrographic notes made on granites of the medium to fine grained type are given below:

Granite from Parkinson group of quarries.

Megascopic character.—Medium-grained to fine-grained gray granite. Biotite, quartz, and feldspar. Mica evenly distributed in fine flakes.

Microscopic character.—Largely composed of microcline with subsidiary orthoclase, rare plagioclase. Micrographic intergrowth with quartz in some feldspar. Rare zonal arrangement. Alteration has set in on nearly all the feldspar. Quartz shows some strain phenomena. Biotite occasionally altered to chlorite. Alteration of feldspar more pronounced at center than elsewhere. Grain or two of magnetite.

Granite from Kansas City quarry, 2 miles west of Llano.

Megascopic character.—Medium to coarse grained light-gray granite with slightly gneissoid aspect. Quartz, feldspar, mica.

Microscopic character.—Thirty-two per cent quartz; 62 per cent feldspar, microcline, and orthoclase; 6 per cent mica (biotite) with rare muscovite; 71 per cent SiO_2. Micrographic intergrowths of quartz and feldspar occasionally finely developed.

Hornblende granite from northwest Hog Mountain, near Wollastonite rock.

Megascopic character.—Pinkish toned medium crystalline granular, spotted with blotches of hornblende of various sizes up to one-fourth inch in diameter. Groundmass between the blotches is barren of ferromagnesian minerals.

Microscopic character.—Microcline, orthoclase, and albite-oligoclase feldspars dominant in order named. Dark-green hornblende apparently poikilitically arranged about quartz. Measurements with microscope show 31 per cent quartz, 69 per cent feldspar, 75 per cent SiO_2.

Granite from Norton quarry.

Megascopic character.—Light-gray granite; abundant mica in very small flakes, evenly distributed.

Microscopic character.—Microcline, orthoclase, and little albite-oligoclase; quartz abundant. Biotite mica.

Red granite from Parkinson's quarry "well," camp No. 1.

Megascopic character.—Red, fine-grained granite, with ferromagnesian minerals scant and in very small particles.

Microscopic character.—Microcline, orthoclase, and albite-oligoclase rather abundant. Quartz abundant. Little magnetite, mica, titanite, and hornblende. Ferromagnesian minerals very scant. Feldspars where altered are replaced by a red decomposition product.

Granite from Grays Mountain.

Megascopic character.—Coarse pinkish granite. Feldspars as large as one-fourth inch in length and mica very abundant; sufficient to give dark tone to rock.

Microscopic character.—Oligoclase and microcline. Former dominant. Both dominant over quartz. Biotite abundant, but not evenly distributed. Apatite. Feldspar altered.

Hornblende granite (a chip only) from south edge of quadrangle near small creek above house in Elver's pasture.

Coarse granite. Orthoclase, microcline, and oligoclase feldspars. Quartz. Hornblende, partly altered to chlorite. Feldspars badly altered. Zircon. Apatite abundant. Titanite.

Pink granite from west of road, east of direct route from Castell to Berry Spring (Goodes Spring).

Megascopic character.—Fine-grained pink granite, containing circular areas impoverished of ferromagnesian minerals, in the center of which are aggregations of titanite and magnetite.

Microscopic character.—Microcline, orthoclase, and albite-oligoclase feldspars with biotite, and segregations of magnetite and titanite. Part of the quartz one of the first minerals to separate out. Apatite needles abundant.

Granite from Heine's well, south of Willow Creek, 4 miles north of river, 1 mile west of San Fernando Creek.

Megascopic character.—Red granite, medium to fine grain, glassy aspect.

Microscopic character.—Microcline and orthoclase feldspars and quartz. Microcline and orthoclase, badly altered. Scanty biotite; chloritized. Sericite developed in feldspars. Red tone very probably accentuated by alteration.

Pink granite from one-fourth mile west-northwest of Esbon post office on Kings Mountain.

Megascopic character.—Fine-grained, light-pink granite, ferromagnesian minerals evenly distributed in tiny flakes.

Microscopic character.—Microcline feldspar dominant; with orthoclase and quartz. Biotite (about average amount) in small flakes. Apatite needles. Feldspar, especially orthoclase, badly altered, though the hand specimen looks fresh.

Granite from breast of crosscut in shaft at Iron Mountain (1908).

Megascopic character.—Pink, medium to fine grained granite.

Microscopic character.—Microcline, orthoclase, and albite-oligoclase feldspars. Quartz. Biotite mica. Little magnetite.

OPALINE QUARTZ-FELDSPAR PORPHYRY TYPE.

This rock, as its name indicates, is a quartz-feldspar porphyry. When rough in the hand specimen, it has a dark-reddish aphanitic groundmass mottled with abundant phenocrysts of pink feldspar and opaline quartz, the quartz being very prominent on weathered surfaces. The quartz phenocrysts break with a glassy fracture, are of light-bluish tone, and possess a certain iridescence when polished. The microscope shows quartz phenocrysts (with a great number of minute inclusions); microcline feldspar phenocrysts; microperthite phenocrysts (albite and orthoclase); a groundmass of quartz and orthoclase, and small flakes of biotite mica; a little magnetite with associated sphene; some fine zircons; little apatite; local chloritization of mica.

Dr. Joseph P. Iddings proposed the name of llanite for this rock some years ago.[a] It is known in Llano County as opaline granite. Dr. Iddings[a] estimated that the rock is probably composed as follows:

Mineral composition of opaline granite, Llano County, Tex.

Quartz	34.6
Feldspar	55.7
Biotite	8.6
Fluorite	1
Apatite	.13

In speaking of the bluish color of the quartz he says:

> The sky-blue milky color of the quartz phenocrysts is undoubtedly due to reflection of blue light waves from the minute colorless prisms whose width is a fraction of the length of light waves. It is similar to the blue color of the sky. It is probable, however, that there is also blue light produced by interference of the light reflected from both sides of the minute tabular crystals, whose thickness is also of the order of a fraction of a light-wave length. So that both kinds of phenomena occur within the quartzes.

SCHISTS AND GNEISSES (LLANO SERIES).

DIVISIONS AND DISTRIBUTION.

The schists and gneisses of this area comprise the Llano series, and all are believed to be of Algonkian age. Two broad divisions may be recognized and have been mapped on Plate III (in pocket)—the one, a series dominantly basic and generally of dark color containing much limestone, biotite, amphibolite, and graphite schists and termed the Packsaddle schist, a name applied originally by Comstock[a] to marbles and shaly beds near Packsaddle Mountain. In this report, however, the name is redefined and limited strictly in its usage by principles to be presented below. The other, a series dominantly acidic, of light color, containing some altered limestone and termed the Valley Spring gneiss, a name also applied by Comstock[b] and also redefined in this report. Bands of acidic material are found in the first series and bands of basic dark material have been included in the second. There is a transition zone between the two series, locally offering difficulties to the placing of definite boundaries. Likewise, within the acidic series, the distinction between invading granites and gneisses is often exceedingly difficult to recognize, because of a gneissoid texture that the granites locally possess.

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[a] Phillips, W. B., Tests on Texas building stones: Mining World, June 24, 1905.

The distribution of the two series is dependent primarily on major structural relations, modified by igneous intrusion. Their general northwest-southeast trend is determined by the major axes of folding, and the lack of continuity along their trends is due to the presence of granite (see Pl. III). Two major anticlinal axes are present, one passing northwest and southeast through the center of the mountainous mass just west of Oxford, the other passing from Packsaddle Mountain northwest to a point several miles west of Babyhead. Between these two anticlinal axes a major synclinal axis passes northwest and southeast a short distance west of Llano. The broad band determined by this synclinal axis is composed largely of the Packsaddle schist, while the anticlinal axes mark areas of the lighter Valley Spring gneiss. The basic Packsaddle schist overlies the acidic type, and therefore is found on the eroded flanks of these great folds, where not disturbed by granite masses. The major axes of folding do not represent a simple structure, minor folds, some of which have been separately mapped, being superimposed upon the major folds, with the result that local complexities of structure are frequent. No estimate has been made of the thickness of the series.

PACKSADDLE SCHIST.

DISTRIBUTION AND GENERAL CHARACTER.

The Packsaddle schist series includes mica, amphibole, and graphitic schists, and crystalline limestone. In the series are also lighter-colored, more feldspathic bands, resembling quartzites. Intrusive rocks of earlier age than the granite, of the diorite-gabbro type, are also present locally in considerable amount. They have been separated from the Packsaddle schist in only one instance, in the southeast corner of the Llano quadrangle and the southwest corner of the Burnet quadrangle.

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[a] Comstock, T. B., Preliminary report on the geology of the central mineral region of Texas: First Ann. Rept. Texas Geol. Survey, 1889.

[b] Loc. cit.

As a whole, the Packsaddle schist is characterized by an excellent cleavage which for the most part accords in attitude with an original bedding in sediments, of which the schists represent the metamorphosed equivalents. Frequently, though not invariably, the graphitic schists are closely associated with limestones. The limestones are developed to a varying degree, as a glance at the map (Pl. III) will show. East of Oxford numerous limestone beds are present, and the region south and west of Llano includes many bands. In general they occur wherever the Packsaddle schist is found, but, though most abundant in the Packsaddle schist and in a measure characteristic of that schist series, they do also occur in the lighter series (Valley Spring gneiss), though usually in a still more altered form; that is, as wollastonite bands. The graphitic schists carry varying proportions of graphite—locally, it is believed, a sufficiently high content to be of commercial value. (See p. 77.) A microscopic examination of a specimen of graphite schist from Cottonwood Creek showed about 60 per cent of quartz, 30 per cent of orthoclase feldspar, fairly abundant grains of augite, a little titanite, a little apatite, and flakes of graphite arranged parallel to the schistosity of the rock. Often crystalline limestone bands are interbedded with the graphite schist, leaving little or no doubt as to the sedimentary origin of the carbon mineral. Among the remaining types of a sedimentary origin are mica, tourmaline, and quartz-feldspar schists. All these rocks carry a high content of quartz, and are characterized by potash feldspar and biotite with here and there some pyroxene (augite). The tourmaline schist is an exception and does not carry feldspar. Magnetite, titanite, and apatite are often accessories. Amphibolite schists are fairly abundant and are characterized by a very low content or lack of quartz. There is some doubt regarding their origin. As they are interbedded with limestones, a sedimentary origin is suggested; their origin as old flows and sill-like intrusions, however, must be kept in mind, as possible or even probable, for basic intrusive rocks are found in the region, and in one place a type transitional from a basic porphyry dike to amphibolite schist was noted. Amphibolites of undoubted igneous origin may also be seen in considerable masses.

The following section was measured on the west fork of Oatman Creek, about 3½ miles south of Llano:

Section of Packsaddle schist on Oatman Creek east-southeast of Bachelor Peak.

	Feet.
Schist with pencil cleavage	1,000
Hidden	400
Thin-bedded feldspar-quartz schist (strike N. 40° W., dip 65° E.).	3
Well-banded hornblende schist	30
Quartzite (feldspar-quartz schist)	1
Hornblende schist	15
Thin-bedded micaceous schist	75

	Feet.
More massive, micaceous schist with pegmatite and quartz injections	130
Graphitic slate schist	23
Crystalline limestone	24
Graphitic slate schist	35
Injection gneiss	30
Hornblende schist	91
Feldspar-quartz schist	62
Weathered hornblende schist	120
Thin-bedded mica schist, massive as a whole	60
Limestone	8
Graphitic slate or schist	6
Limestone	4
Heavy, thin-bedded mica schist full of quartz blebs and stringers.	32
Friable mica schist (like pencil schist)	250
Hidden	40
Mica schist	50
Hidden	50
Mica schist	20
To granite contact	60
	2, 619

PETROGRAPHY.

The results of a microscopic examination of a number of specimens of the Packsaddle schist are as follows:

Quartz-feldspar schist.

Megascopic character.—A whitish-pink, sugar-grained, finely banded rock; bands straight and narrow, made by pink and white constituents. Speckled with magnetite showing a slight tendency to follow bands. Rock cleavage follows bands.

Microscopic character.—Equidimensional grains microcline feldspar, orthoclase feldspar, and quartz. Flakes of a brownish-yellow biotite mica and magnetite not clearly in bands. Considerable alteration of feldspar. Measurements showed 68 per cent feldspar, 32 per cent quartz—which gives 76 per cent SiO_2, approximately 12 per cent Al_2O_3, and approximately 12 per cent K_2O.

Quartzite-like feldspar schist.

Megascopic character.—Fine-grained, almost aphanitic, grayish and pink banded schist.

Microscopic character.—Even granular, fine-grained, holocrystalline rock, two-thirds orthoclase feldspar (altered), one-third quartz, light-green hornblende (partly altered to chlorite), and titanite. About 75 per cent SiO_2 and 12 per cent Al_2O_3.

Amphibolite schist.

Megascopic character.—Dark-green to black, finely-cleaved schistose rock.

Microscopic character.—Mass of hornblende laths in a matrix of feldspar. Abundant grains titanite. Little calcite, little apatite.

Amphibolite schist.

Megascopic character.—Dense, slaty, almost aphanitic, dark-green to black rock showing on weathered surface evidence of schistosity.

Microscopic character.—From 50 to 60 per cent light-green hornblende, considerable augite, orthoclase, and some plagioclase feldspar in the interstices of the hornblende laths.

Amphibolite schist.

Megascopic character.—Dark-green to black glittering schist.

Microscopic character.—Linear arrangement of abundant dark-green hornblende laths in a matrix of microcline and quartz, the former in great excess. Scattering grains of augite partly altering to hornblende. Epidote, magnetite, apatite.

Amphibolite schist.

Megascopic character.—Dark-green to black very fine grained glittering schist.

Microscopic character.—Interlocking grains of prismatic light-green hornblende evenly though not entirely equidimensional. The little space between the hornblende plates is filled with feldspar.

Biotite-quartz-mica schist.

Megascopic character.—Gray even and fine grained mica schist.

Microscopic character.—Even, granular quartz, orthoclase, and microcline. Abundant biotite laths parallel to schistosity. Some muscovite.

Mica schist.

Megascopic character.—Gray banded schist. Bands due to lines of pink feldspar in light-gray background. Feldspar is arranged in lentils which produce the bands. Abundant fine flakes of black mica.

Microscopic character.—About equally divided quartz and altered orthoclase feldspar. Abundant biotite in linear parallel arrangement. Abundant iron oxide grains.

Mica schist.

Megascopic character.—Dark-greenish, nearly black aphanitic glassy rock showing on surface striations which reveal its schistose nature.

Microscopic character.—Orthoclase and quartz in equidimensional grains, former in slight excess. Biotite mica in fine parallel alignment. About 6 to 9 per cent mica.

Quartz-tourmaline schist.

Megascopic character.—Dense dark-blue to black hornfels-like rock, with fine bands of quartz showing schistosity.

Microscopic character.—Fine bands of quartz and tourmaline. Tourmaline for the most part oriented parallel to schistosity and apparently crystallized first, as it appears in fine lines in the quartz parallel to bands. Much of the quartz has wavy extinction.

Biotite feldspar gneiss.

Megascopic character.—Blue-gray, granular, fine-grained rock with gneissoid aspect, rather evenly granular. Mica prominent as dark constituent.

Microscopic character.—Granitoid texture. Quartz, albite-oligoclase, and abundant biotite. Some hornblende, titanite, and chlorite. By measurements the following approximate chemical composition was calculated: 73 per cent SiO_2, 14 per cent Al_2O_3, 6 per cent Na_2O, 1 per cent CaO, 6 per cent Fe, Mg, etc.

Mica schist.

Megascopic character.—Pink and black banded schist, with finely developed schistosity due to mica.

Microscopic character.—Crystalline granular quartz. Microcline and little albite-oligoclase. Biotite, in laths or plates parallel to the schistosity. Quartz arranged roughly in direction of schistosity. Microcline is slightly altered. Composition: 79 per cent silica, 9.64 per cent alumina, 8 per cent potash, 3.36 per cent iron, magnetite, sodium, and calcium.

VALLEY SPRING GNEISS.

DISTRIBUTION AND GENERAL CHARACTER.

The mapping of the Valley Spring gneiss was locally attended with many difficulties, partly connected with separating it from the Packsaddle schist, but primarily because of its relation to granitic intrusions, which, as has been pointed out, are widespread and of all degrees of magnitude. As the Valley Spring gneiss often closely resembles the granites, especially where slight schistosity may have been impressed upon the granites, and as contacts are exceedingly irregular (a feature characteristic of the borders of large intrusive masses), all the boundaries shown on the map must not be considered as definitely separating distinct formations, but rather as indicating changes in the dominant rock type. In a region where intrusion has so completely interleaved and at places actually impregnated a rock mass, and where all gradations from pure granite to pure schist exist, such boundaries as have been used are necessary to express the geologic facts. In many places, however, the boundaries are sharp and form definite lines, but it is not practicable on the map to discriminate between the two classes of boundaries. It is believed, also, that with the schists and gneisses of sedimentary origin are included old gneisses of igneous origin.

Perhaps the most distinctive difference between the light Valley Spring gneiss and the dark Packsaddle schist lies in their difference of massiveness. This difference applies more particularly when the groups are taken as a whole and not when small areas are compared. The mountainous tract west, southwest, and northwest of Oxford, including Hobson and Blount mountains, and the area south and west of Babyhead, and including Babyhead Mountain, contain such massive rocks, typically representing the Valley Spring gneiss. A study of these areas leaves the impression that a thick series of sediments of rather uniform composition has been involved in a zone of intense granitic intrusion and metamorphism, locally in a zone where rock flowage and minor folding have been dominant. The dark Packsaddle schist nowhere presents as a whole this massive appearance.

It has already been noted that dark bands occur, though not abundantly, in areas mapped as Valley Spring gneiss, and also bands composed of the metamorphosed equivalents of limestones—that is, wollastonite. These bands of wollastonite lend plausibility to the hypothesis that metamorphism has been most intense in the light series (the lower series), though this hypothesis does not exclude the generalization that intrusion has been most intense along synclinal axes, as the position of the great granite areas indicates, for evidently wherever the dark series is nearly obliterated by areas of granite the underlying light series must have been similarly affected.

PETROGRAPHY.

The results of a microscopic examination of a number of specimens of the Valley Spring gneiss are given below.

Feldspar-quartz-mica gneiss.

Megascopic character.—Finely banded sugar-grained pink and black gneiss. Bands one-sixty-fourth to one-fourth inch in width.

Microscopic character.—Potassic feldspar, more or less altered, and quartz about evenly divided with feldspar. Biotite mica (altered to chlorite in part) in linear arrangement. Little calcite. Little apatite.

Feldspar-quartz schist.

Megascopic character.—Nearly white aphanitic schist. Banding due to quartz bands separated by 1-inch to ½-inch aphanitic bands.

Microscopic character.—Fine-grained, granular quartz and microcline, the former much in excess. Feldspar greatly altered. Little muscovite.

Quartz-feldspar schist.

Megascopic character.—Pink, fine sugar-grained rock with only slight schistosity in hand specimen. Flecked with small grains of magnetite evenly distributed.

Microscopic character.—Altered microcline feldspar dominant. Little albite-oligoclase. Quartz abundant, though less than feldspar. Few flakes of biotite. Magnetite scattered.

Quartz-feldspar schist.

Megascopic character.—Even-toned pink fine-grained rock. Banding brought out by quartz and feldspar, arranged in lines. Fine dust of magnetite, little muscovite, and little garnet.

Microscopic character.—Holocrystalline grains quartz, potash feldspar, mostly microcline, and abundant muscovite. Approximate composition: 68.6 per cent silica, 16 per cent alumina, 11 per cent potash, 1.48 per cent calcium, 2 per cent magnetite.

ORIGIN OF THE SCHISTS AND GNEISSES.

The schists described above, those of both the light and the dark series, are all completely crystallized; that is, the arrangement, the size, and the composition of their mineral constituents are due in part to the influence of heat and pressure and in part to flowage as a mass. The presence of crystalline limestones and of graphite and mica schists, traceable for long distances and retaining the characteristics of beds, leaves no room for doubt that these rocks were in great part formed by metamorphism from a sedimentary series. It is believed also that the presence of iron ores leads to the same conclusion—a point which will be more fully considered at another place. As has been pointed out, the amphibolites, because of their basic character, probably represent in part old basic intrusives or flows, or perhaps sediments of a tuffaceous nature.

Gneisses derived by metamorphism from intrusive rocks of a granitic type are almost without doubt present in the region. One crosscutting dike possesses much the same schistose nature as the beds which it cuts. Red Mountain also, a granitic ridge in the southeast corner of the Llano quadrangle, is a noteworthy example of the same phenomenon. This ridge trends northwest, and the dike which forms it can be traced to a point near Walker Peak. Toward the northwest a gradual change takes place in the appearance of the mass, and the rock at its northwest end shows decided lamination. Indeed, were the rock exposed only in the condition seen at this end, it could not be distinguished from beds which are believed to represent sedimentary strata.

In the area immediately east of Long Mountain also the gneissoid rocks have much the aspect of granites impressed with foliate structure; and south of Field Creek, near San Fernando Creek, in the northwest part of the quadrangle, similar features were noted. It should be understood, then, that the series of gneisses and schists of the acidic type mapped as Valley Spring gneiss probably contains material of igneous origin. It may be said here that no genetic relation could be shown between the iron-ore deposits and these old granitic intrusive rocks.

BASIC INTRUSIVE ROCKS OF A GABBRO-DIORITE TYPE.

GENERAL CHARACTER AND DISTRIBUTION.

The dark intrusive rocks are most abundantly developed in the southeast corner of the Llano quadrangle, and, though they have not been generally separated from the accompanying dark Packsaddle schist, they have been mapped in one instance. A considerable mass of gabbro was observed in the vicinity of Goldmine Creek, north of Moss ranch, but it has not been mapped; and, as has been stated, the dark Packsaddle schist probably includes amphibolites, which represent old intrusive rocks of gabbroic or diabasic type.

The area south of Click is especially characterized by very dark green to black amphibolite rocks, which were probably derivatives of a gabbro or diorite magma. The talc deposits in this vicinity are alteration products of such a series, and the serpentine rocks of Oxford are probably derived from a peridotitic magma.

Two dark fine-grained dikes (aphanitic in texture) which cut the schist series and which might have been expected to show a rather basic character proved to be felsites, one a spherulitic mica felsite, the other a hornblende-mica felsite; the hornblende of this latter rock showed a bluish pleochroism parallel to the C axis, suggestive of a soda amphibole. A short distance east of Click a small intrusive mass proves to be a hornblende-soda granite.

The rocks of this gabbro-diorite group were intruded earlier than the greater part of the granites. It is possible that some of the latter rocks, which show evidence of pressure and metamorphism, may have been nearly of the same age, though no relations were observed which might establish this point.

PETROGRAPHY.

The results of a microscopic examination of a number of specimens are as follows:

Soda-hornblende granite, chip only, taken a short distance east of Click post office.

Microscopic character.—Holocrystalline albite feldspar and considerable quartz; a little microcline feldspar. Large plates of green hornblende are abundant. Abundant titanite surrounding grains of titaniferous magnetite. The rock has suffered crushing and shows abundant granulation at the edges of the feldspar grains; the amphiboles are locally broken and bent and drawn into shreds.

Hypersthene olivine gabbro from Goldmine Creek.

Megascopic character.—Dark-blue to black medium-grained rock.

Microscopic character.—Holocrystalline texture. Labradorite in lathlike prisms. Diallage, hypersthene, and olivine. Biotite and hornblende poikilitically inclosing pyroxene and feldspar. Magnetite.

Amphibolite from high hill on Coal Creek.

Megascopic character.—Dark-green hornblende rock with slight tendency, due to pressure, to cleave more easily in one direction than in another.

Microscopic character.—Mat of light-green hornblende with plagioclase feldspar in interstices. Shows evidence of crushing.

Metadiorite porphyry in hornblende schist series near Aaron Moss ranch.

Microscopic character.—Altered andesine-labradorite feldspar phenocrysts in a fine-grained groundmass of feldspar and green hornblende. Flowage of hornblende around the phenocrysts of feldspar noteworthy. Shows an intermediate stage in the formation of an amphibole schist.

Diorite from Cedar Mountain under Cambrian.

Megascopic character.—Medium-grained dark gray to green rock.

Microscopic character.—Holocrystalline andesine-labradorite and hornblende in large plates.

Spherulitic mica felsite.

Megascopic character.—Black aphanitic dike rock.

Microscopic character.—Mass of very fine blades of biotite mica in groundmass of unstriated feldspar. Some quartz and one quartz phenocryst, showing absorbed edges. A spherulitic arrangement of the feldspar is noteworthy and the mica seems to be arranged in a manner controlled perhaps by this spherulitic structure.

Amphibolite (meta-gabbro?) (partly crushed) from southwest part of Burnet area near edge of Llano area.

Megascopic character.—Dark-green medium to fine-grained hornblende rock.

Microscopic character.—Mass of interlocking hornblende crystals with interstices filled with untwinned plagioclase feldspar. Abundant grains of magnetite largely within the hornblende.

Mica-hornblende felsite.

Megascopic character.—Nearly black aphanitic dike rock.

Microscopic character.—Abundant hornblende in laths and grains set in a matrix of very finely granular feldspar and quartz. Biotite mica is also abundant in fine laths and tiny plates. Apatite needles are present. The hornblende has a blue pleochroism parallel to the elongation (C), and extinction angles as high as 18°.

Diorite from southeast of Rough Mountain and west of San Fernando Creek.

Megascopic character.—Medium-grained dark-green rock.

Microscopic character.—Holocrystalline texture. Weathered andesine-labradorite feldspar and abundant hornblende in large plates. Much pyrite in large part confined to hornblende. Hornblende altering to iron oxide along cleavage cracks. Some epidote. Some apatite.

PALEOZOIC ROCKS.

The Paleozoic formations in the Llano-Burnet region, as stated in an earlier portion of this report, surround a basin cut in pre-Cambrian rocks, and much of the section therefore is exposed about the edges of this relatively low-lying area.

The pre-Cambrian rocks, composed in large part of metamorphosed marine sedimentary beds, passed through all the stages of deposition, deep burial, folding, metamorphism, intrusion, elevation, erosion, and subsidence beneath the sea before the basal Paleozoic beds were deposited. It is evident, therefore, that a vast interval of time separates the periods during which the two series were formed. This time interval is expressed by the unconformity between the Paleozoic beds and the underlying schists and granites. As this report treats principally of the pre-Cambrian rocks and the relations of the economic resources thereto, the Paleozoic rocks will be very briefly discussed.

UPPER CAMBRIAN ROCKS.

The Upper Cambrian rocks of this area are believed to be essentially the equivalent of the Reagan sandstone in Oklahoma. They rest upon a pre-Cambrian complex of metamorphic rocks—the schists, gneisses, and intrusive rocks described above—and have been divided into three formations, namely, proceeding from the base upward, the Hickory sandstone, the Cap Mountain formation, and the Wilberns formation.[a]

A variable thickness of conglomerate and sandstone, up to 250 feet, comprises the lower formation to which the name Hickory sandstone is given, a name originally applied by Comstock[b] to sandstones in the valley of Hickory Creek and its tributaries. Next, but with a gradual transition from sandstone to limestone, are beds predominantly limestone, capped by a variable thickness (from 15 to 75 feet) of cross-bedded glauconitic sandstone; these strata, 90 feet thick, constitute the second formation, the Cap Mountain, which is typically exposed at Cap Mountain, in the Llano quadrangle. The third formation, the Wilberns, from 170 to 220 feet thick, includes limestones and shales, the shales occupying approximately the upper third of the formation. It is typically exposed near Wilberns Glen, in the Llano quadrangle.

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[a] For detailed descriptions of these formations see Llano-Burnet folio, Geol. Atlas U. S., U. S. Geol. Survey. (In preparation.)

[b] Comstock, T. B., Preliminary report on the geology of the central mineral region of Texas: First Ann. Rept. Texas Geol. Survey, 1889.

CAMBRO-ORDOVICIAN ROCKS.

The Cambro-Ordovician rocks have not been subdivided. They are represented by the Ellenburger limestone (locally dolomitic).[a] There is believed to be an unconformity near the top of the formation, for, according to Ulrich, fossil evidence precludes the idea that continuous sedimentation could have been in progress during the deposition of the entire series of beds. The formation is composed of chert-bearing limestones and dolomites, which are typically exposed in the Ellenburger Hills, in the Burnet quadrangle. In the greater number of places where the base of these beds was observed, apparent conformity with the Wilberns formation existed, though in several places on Riley Mountain an angular limestone conglomerate was present. Here, also, some evidence of overlap was observed, but the writer, in view of the fact that faulting was found to be prevalent, wishes to leave this point open until opportunity may be offered to study the locality again. In the majority of places, however, where the conglomerate was noted, concordance of beds was the rule. Many observations were made where no unconformity could be detected, and also where apparent transition of the two formations could be followed. It must be noted, however, that the basal beds of the Ellenburger limestone varied in texture and appearance; and as this phenomenon is in itself a suggestion of unconformity, any conclusion must for the present remain tentative.

At the top of the Ellenburger limestone a conglomeratic limestone bed is generally, though not always, present, and the lowest portion of the upper Carboniferous succeeds. The deposition of upper Carboniferous limestone on beds of Cambro-Ordovician age marks a great gap in sedimentation, a period of great duration including lower Carboniferous, Devonian, Silurian, and part of Ordovician time, during which no deposition was taking place.

The Cambro-Ordovician rocks occur at the crest of the Paleozoic scarp (unless faulting has intervened) and form the greater part of the Paleozoic surface in Llano and Burnet Counties.

Complete sections of the Ellenburger limestone are not easy to obtain. The general massiveness of the formation, gentle folds and faults, combine to prevent continuous record. Thicknesses up to 600 feet may be observed in the bluffs of the Colorado, between Tanyard Crossing and Deer Creek, and it is probable that the formation is composed of beds aggregating 1,000 feet in thickness.

CARBONIFEROUS ROCKS.

Beds of Carboniferous limestone and shale of lower Pennsylvanian age are present in this region and have been divided into two formations—the Marble Falls limestone, composed of limestone, and the

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[a] For detailed description of the formation see Sidney Paige, Llano-Burnet folio, Geol. Atlas U. S., U. S. Geol. Survey. (In preparation.)

Smithwick shale,[a] composed of nearly black shale accompanied by sandstone lentils.

As has been already noted the Carboniferous is in most places separated from the underlying Cambro-Ordovician by a thin limestone conglomerate, and, in one instance, a very coarse, angular conglomerate or breccia was observed. In some localities, however, little or no discordance could be seen, as in the restricted basin 5 miles northeast of Blufton in the Burnet quadrangle.

The Marble Falls limestone is believed to be not over 450 feet, possibly 500 feet, in thickness. The Smithwick shale, which immediately overlies the Marble Falls limestone, because of its soft nature is not exposed in such attitude as to permit a section measurement. Moreover, its top is overlapped by Cretaceous sediments. Probably the beds exposed in Burnet County do not exceed 400 feet in thickness.

The Carboniferous is confined almost entirely to the southeastern portion of the Burnet quadrangle, though a small area exists in Riley Mountain.

STRUCTURE.

A reference to the small map of Texas (Pl. I, p. 7), showing the geologic relations of the Llano-Burnet region and surrounding area, will immediately call forth the suggestion that some unusual condition has caused the exposure of these ancient pre-Cambrian rocks; and on turning to the detailed map (Pl. III, in pocket) and studying the faulting which has taken place, one is compelled to ascribe to this faulting, combined with differential erosion, the present basin-like form of the area.

The faults which border this basin, indicated by heavy black lines, all have one important similarity. The downthrown block forms the scarp side of the fault and presents a more or less vertical face toward the basin, or, in other words, the basin area, now topographically lower than the surrounding scarp and largely characterized by pre-Cambrian rocks, is structurally elevated with respect to that scarp.

Such an elevation in past time must have exposed the rocks which were carried up by it to accelerated attack by the elements with the result that the overlying sediments were stripped off and the core of schists and granite uncovered. From this point on, the metamorphic complex disintegrated more rapidly than the surrounding linestone-capped strata, and the present erosional basin was formed. The Paleozoic sediments involved in the suggested uplift are locally folded, and are inclined at varying degrees from the horizontal.

The structure of the pre-Cambrian schists (except the displacement they have suffered due to late faulting) is of a much earlier date and of a much more complex nature than the structures just described.

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[a] For detailed descriptions of the Smithwick shale see Llano-Burnet folio, Geol. Atlas U. S., U. S. Geol. Survey. (In preparation.)

The rocks have suffered deep-seated regional metamorphism, have been impressed with a foliate structure, have usually steeply inclined dips, trend generally to the northwest, and are intruded both by old dioritic and gabbroic rocks and by late granitic and pegmatitic types. The major structural lines are indicated on the geologic map (Pl. III). Two nearly parallel anticlinal axes are specially noteworthy, one a few miles west of Oxford, the other, a few miles east of Lone Grove. The latter ends to the southeast in the Burnet quadrangle (not shown here), and is beautifully accentuated by heavy bands of limestone, bending around the nose of the arch.

Several of the many minor folds are indicated on the map. The great granite masses occupy positions corresponding to synclinal axes, as, for example, the mass in the southwestern part of Llano quadrangle and the mass in the western part of Burnet quadrangle. The central syncline does not seem to have suffered such intense intrusion.

North of Llano River in the western portion of the Llano quadrangle the anticlinal arch flattens and the schists dip at lower angles.

The manner in which intrusion has taken place has already been described and need not be repeated. A study of the map will indicate, in part, the extreme point to which this process has been carried. A discussion of the probable forces involved in the production of the post-Paleozoic faulting can not be given in this paper.

IRON ORES.[a]

GENERAL DESCRIPTION.

By A. C. Spencer.

Iron ores composed essentially of magnetic iron oxide (magnetite) (Fe_3O_4) or of admixtures of magnetite with hematite (Fe_2O_3) occur in deposits of noteworthy size in Llano and Mason Counties, Tex. During the progress of geologic mapping of the Llano quadrangle in 1908 and 1909 thirty-two more or less distinct occurrences of such iron ore were noted and studied with such detail as was warranted by generally poor natural exposures and a very small amount of exploratory development.

Though a few localities are in eastern Mason County, most of the iron showings are in that portion of Llano County which lies north of Llano River. All of the known occurrences of magnetite are described, but it is believed that not more than perhaps three of the deposits promise to become of industrial value. No assurance can be given that the three most likely deposits can be developed into profitable mines in advance of adequate exploration by means of diamond drills or by prospecting shafts in addition to those already opened, and it is considered that the less promising deposits will not warrant any large expenditure for prospecting unless the market value of iron ores increases.

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[a] The examination of the iron-ore deposits was assumed as an especial task by Mr. Spencer in view of his familiarity with the magnetite ores of the northeastern portion of the United States, but the more notable showings were also studied by Mr. Paige. The notes of both have been used in the following descriptions.

The permissible scope of the geologic work did not admit of magnetic surveys, but it is suggested that such surveys should be carried on in connection with any future exploration of the more promising magnetic deposits of this district. Surveys with compass and dip needle would perhaps serve as adequate guides in the preliminary magnetic exploration of these iron-ore deposits, after which, if the results obtained warranted such a course, more refined methods and studies might be applied.

Financial interests that may take up the problem of the practical development of the Llano County iron ores will doubtless give due consideration to the possibility of applying magnetic concentration, as processes of this sort are becoming more and more firmly established in various parts of the world.

The deposits of magnetite in Llano and Mason counties, Tex., are typically layered or stratiform ore bodies conforming in attitude with the layering of the somewhat schistose rocks by which they are inclosed. The feature of layering is more marked in the leaner ore bodies than in the deposits of higher grade, but may be made out in nearly every locality where the ore-bearing rocks are adequately exposed for any sort of an examination. A single exception is noted in the case of a small ore mass opened by the Gallihaw shaft, which occurs in a dike cutting across the layering of the local gneiss.

In so far as the geologic mapping may be relied on the deposits are associated mainly with the lower of the two sets of gneisses which have been broadly separated. The difficulties of consistently discriminating between these rocks have, however, proved to be so great that it must be freely admitted that the immediate country rocks of the ores may be representatives of the upper set of schists in certain localities. If any mistake has been made in the proper classification of the country rocks, it is in places where the upper schists have suffered excessive metamorphism and where they constitute areas of minor extent.

Two extensive occurrences of magnetite were found within areas which are undoubtedly underlain by the upper dark schists, the Packsaddle schist, and a small amount of magnetite was noted at one other place in this rock. The Olive deposit, which is included in the foregoing, occurs in the dark Packsaddle schist near beds of limestone and very near the edge of a great intrusion of coarse granite.

SPECIAL LOCALITIES.

OLIVE PROPERTY.

By A. C. Spencer.

The Olive iron-ore property is located on Little Llano River about 6 miles east by northeast of Llano, 1 mile south of Lone Grove post office, and 1 mile north of Llano River and the line of the Houston & Texas Central Railroad. The property has been more extensively developed than any other in the district. It was opened by a shaft in 1892 or 1893.

An extensive area of granite covering the western-central part of the Burnet quadrangle and the adjacent portion of the Llano quadrangle is bounded on the southwest and west by a band of limestone-bearing schists extending along the railroad southeast and northwest from Graphite station and up the valley of Little Llano River. The Olive shaft is situated on the east bank of the Little Llano just west of the main boundary between the schists and granites, and therefore within the schists which belong to the upper set of metamorphosed sedimentary rocks characteristic of the region.

The rocks exposed in the vicinity include granite, hornblende-mica schist, graphite schist, and crystalline limestone. The granites are intruded into the other rocks in an intricate manner which can not be fully made out because of rather poor exposures, so that the representation of areal relations given on the geologic map is of necessity very much generalized. The material on the waste dump includes all the rocks mentioned except graphite schist.

The stock pile contains perhaps 400 tons of ore of very good physical appearance. Most of the ore contains hornblende, and some of it carries iron sulphide in addition to magnetite. It is all more or less distinctly layered in its make up. As the result of 17 years' exposure many of the ore chunks present a somewhat weathered appearance, the partial disintegration being due to oxidation of the iron sulphide present. Where this mineral is lacking, the ore shows no effects of weathering.

The following analyses show the character of the ore:

Analyses of iron ore from Olive mine, Llano County, Tex.

	Metallic iron.	Silica.	Sulphur.	Phosphorus.
1	57.80	8.40	0.28	Trace.
2	54.35	10.16	.55	.021
3	57.5	8.6	Trace.	Trace.

1 and 2 are samples taken by Robert Linton, of Atwater, Linton & Atwater, mining engineers, for Johnston, Elliot & Co., of Dallas, Tex.
3. S. H. Worrell, analyst, University of Texas.

Mr. Robert Linton has furnished also the following analyses, said to have been made in 1893 for the owners of the Olive property. Though the name of the analyst is not given, there is no reason to believe that these are not good commercial analyses. The samples taken together are stated to have come from the third mine level and to represent a section across 9 feet 6 inches of ore, 9 feet 2 inches of which is covered by samples 5 to 11 in the following table. These samples show an average content of iron of 58.71 per cent and of phosphorus of 0.0325 per cent, this average being figured with due consideration of the widths of ore stated in the table.

The analyses show a strictly Bessemer type of ore with a moderate iron content. Sulphur, though rather high, is not sufficient to lower the value of the ore appreciably.

Analyses of iron ore from third mine level, Olive mine, Llano County, Tex.

Analysis No.	Width of ore.		Fe_2O_3.	Fe.	P.	S.	SiO_2.	Mn.	TiO_2.	Total.
	Ft.	*in.*								
5	2		91.76	64.33	0.0264	0.58	81.52	....	....	100.51
6		1	87.17	61.02	.0177	.93	11.08	2.25	....	101.44
7		2	....	24.08	.0607	2.21	25.28	....	....	....
8	2	3	89.27	62.49	.0104	.32	8.87	....	....	98.47
9	2		69.81	48.87	.0279	.64	19.43	....	....	89.90
10		10	60.50	42.35	.0569	.53	22.41	....	....	83.49
11	1	2	61.06	42.74	.0663	.47	25.14	....	....	86.73
12		8	88.34	61.84	.0168	.64	10.54	....	....	99.53

The Olive ore was discovered at a point about 95 feet north by northeast of the working shaft. There is no surface showing and the ore is said to have been uncovered by accident in a shallow excavation. The first development was by means of an incline about 30 feet deep and of a southerly drift, which was afterwards connected with the vertical working shaft. The latter, which was started in the hanging wall, encountered the ore below the level of the drift mentioned above. It was carried down through and below the ore, and three crosscuts were run out to the ore.

The following notes by J. B. Dabney, former superintendent of the Olive mine, are furnished by Mr. N. J. Badu, of Llano:

> The vein lies northeast and southwest. The ore was good on the first heading, but not so good as on the second, third, and fourth levels. On the fourth level the ore pinched to 2 feet. The heading on this level was carried 20 feet beyond the vein and then abandoned. Next an incline was driven to the vein which, as near as I can remember, was 8 feet wide. From the bottom of the incline the vein was opened to right and left.

The cross section of the mine given herewith (fig. 2) is adapted from a sketch by Mr. Dabney on the sheet bearing the notes already given. On his sketch he notes the thickness of the vein above the first level as 3 feet; between the first and second levels, 6 feet; between the third and fourth levels, 8 feet; at the fourth level, 2 feet; and at the bottom of the incline, 8 feet.

For the sketch plan of the mine workings here given the writer is indebted to Mr. Robert Linton, who secured it from mine records which passed through his hands during the summer of 1909.

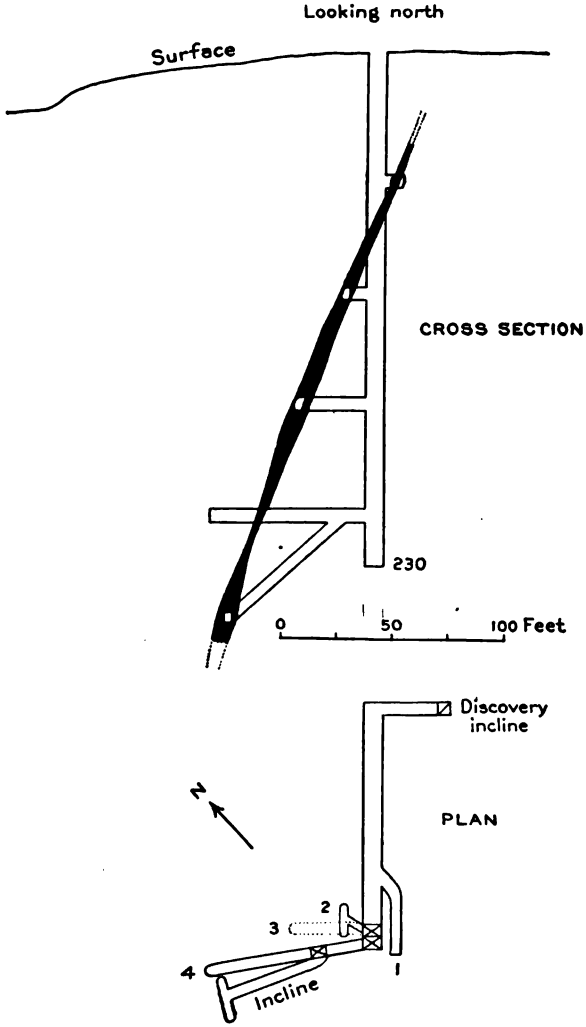

FIGURE 2.—Cross section and plan of Olive mine.

From the data at hand it may be concluded that the Olive ore body strikes approximately northeast and southwest and dips rather steeply toward the northwest and beneath Little Llano River. The relative positions of the mine levels and the apex of the vein at the discovery shaft suggest that the ore body may be a pod-shaped mass, plunging in a southerly direction, but it is not known that any horizontal limit of the ore was established at any point.

Observable relations at the Olive mine do not lead to any conclusion concerning the mode of origin to be assigned to the deposit. Lying at the edge of a great granite intrusion, the ore might have been segregated as an effect of igneous metamorphism. However, the material on the waste dump can not be regarded as in any way particularly characteristic of intense igneous metamorphism, the limestone and schist being quite like the general run of the rocks which compose the upper of the two sets of schist (Packsaddle schist) which have been delineated on the geologic map. The Olive deposit is one of two which may be assigned to this set of rocks without reservation.

It is suggested that magnetic observations might prove of practical value in any future exploration of the Olive ore body.

BADER TRACT.

By A. C. Spencer.

The property known as the Bader tract lies about 9 miles west of Llano and 9 miles south of the Iron Mountain mine. This parcel is adjoined upon the north by a tract known as the Otto, the east and west property line being somewhat less than 2 miles north of Llano River. Iron ore has been found at several places along a north by northwest trending zone about 500 feet in width and nearly 7,000 feet in length. A shaft in the extreme southwest corner of the Otto tract encountered magnetite, which represents the most northerly known extension of the Bader ore range. Farther northwest there is no trace of any exploratory work such as trenches, and careful search on the part of the geologists failed to reveal so much as a fragment of magnetite beyond the west line of the Otto tract. That the ore may continue in this direction is thought to be possible but improbable.

There is much more granite north of the Otto workings than on the Bader tract, and the metamorphic rocks are seriously broken and interrupted by the granite intrusions. This fact is shown in a very general way on the geologic map, though many slivers of schist are present in the areas which the map shows as granite. The impossibility of adequately representing the actual relations of the schists and the granites has been explained in former paragraphs.

No importance can be attached to any suggestion that might be made in the direction of correlating the Bader range with other occurrences of magnetite in Llano County. There is no adequate reason for regarding the range as in any way the extension of the Iron Mountain ore. Though the trend of the range would carry it to the ore on the Epperson tract 3 miles to the northwest, there is a wide area of intrusive granite north of the Bader, and beyond this intrusion structural trends are rather northerly than northwesterly.

A sketch map (fig. 3) has been prepared to show the general distribution of magnetite occurrences on the Bader and the adjacent tracts. Aside from very shallow pits or trenches at various points, the Bader range has been explored only in the vicinity of the northern end, where the original surface indications appear to have been the best. Here trenches and float ore extend for a total distance of 1,000 feet in a southerly direction from the Otto shaft. Two lines of outcrop about 80 feet apart are noted in the vicinity of the Bader incline.

South of the incline and about 110 feet distant an excavation in the lower ore layer shows 31 inches of fairly clean ore dipping about 30° NE. There is also a 5-inch rider lying 2 feet above the principal ore layer and separated from it by feldspathic gneiss. In an adjacent opening on the upper layer the grain or layering of the ore appears to be nearly horizontal.

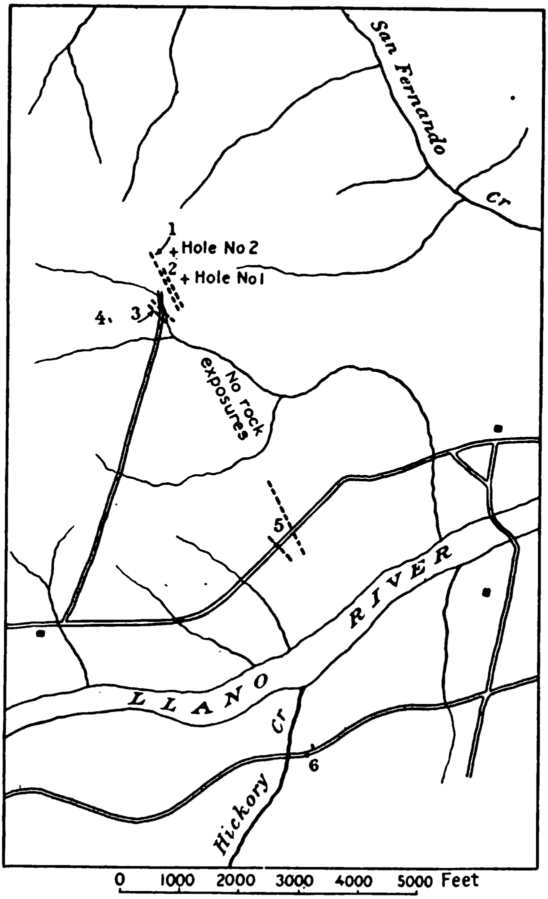

FIGURE 3.—Distribution of float and outcrops on Bader tract and vicinity. 1 Otto shaft; 2, Bader incline; 3, magnetite float; 4, barite-magnetite outcrop; 5, magnetite float and shallow pits; 6, Hickory Creek outcrops.

The Bader incline reveals two ore layers estimated to lie between 10 and 15 feet apart. The dip of these layers varies from 20° to 40°. The lower ore may be described as gneiss carrying thin and discontinuous layers of magnetite. This lean material is not over 16 inches in thickness. The incline follows the dip of this ore for about 25 feet to a point where the slope flattens so that the workings cut across the layering of the gneiss and encounter the upper ore bed. As exposed in the sides of the incline this second layer has a maximum thickness of 20 inches.

The dip length of the incline is estimated to be about 50 feet. All the ore on the dump is layered to a marked degree, much of it being sharply segregated into layers of more or less granular magnetite and layers of silicate minerals.

Standing on the surface one may judge that the lower of the two layers shown in the pits mentioned above is identical with the upper of the two opened by the incline, though this may not be affirmed. If this identification be correct there are at least three ore layers at this place, the lowermost being nowhere exposed at the surface. The approximate positions of the last two holes which have been drilled are given on the sketch map. No record of hole No. 1 is at hand. The following drill log is taken from a private report by E. V. D'Invilliers, who states that this record was furnished by G. M. Wakefield.

Copy of record of drill hole No. 2, Bader location, Llano County, Tex.

[Signed by Fred A. Wright, engineer in charge.]

	Ft.	in.
Stand pipe	1	6
Granite	301	6
Magnetite ore mixed	40	3
Granite	29	9
No core, probably ore	13	
Granite	27	
Chloritic rock and granite	6	
Ore	7	
Granite schist	13	
Granite	55	
Total drilled	494	

Angle of dip 29.5° E.
Strike of formation north-northwest and south-southeast.
Distance from cropping to point where drill was placed 600 feet.

Just where the wagon track from the south crosses the shallow valley southwest of the Bader shaft there is a heavy accumulation of magnetite float in solid pieces ranging up to 1 foot in diameter. This material, which is evidently derived from the veins that are in place on the hill slope to the east, is much more prominent than the float occurring along the veins themselves.

West of the wagon track two lines of magnetite débris may be made out, though it is impossible to trace these lines for any great distance. No trenching has been done at this place. About 1,000 feet west of the wagon track shown on the sketch map (fig. 3) and just south of an east-west wagon road long abandoned is a small outcrop of magnetite mixed with barite ($BaSO_4$). Only a few square inches of this material are exposed and its relations are unknown.

Along what may be called the main trend some float ore may be found to a distance of 500 feet southeast of the Bader shaft, where granitic material appears to interrupt the continuity of the ore. Though gneiss is present north and east of the small stream beyond the granite, no ore fragments are found in the soil. Farther to the southeast and across the stream there are no rock exposures for a distance of 3,000 feet, though a few small pieces of magnetite were noted northwest of the tributary plotted on the sketch map. South of this tributary a series of pits and small pieces of float from place to place show the presence of magnetite for a distance of 2,800 feet along a southeast trend in line with the northern ore occurrences. Also opposite the south end of this line of showings a second line of ore indications is present. Along this general zone the soil is much redder than elsewhere in the neighborhood.

On the sketch map (fig. 3) two occurrences of magnetite on the Mason-Llano road south of Llano River and east of Hickory Creek are indicated. Fragments of ore lying on the surface are massive and pure, but the size of the ore bodies in place can not be judged, as no work has been done upon them.

The ore occurrences at the Hickory Creek locality lie at the end of a curving tongue of more or less hornblendic gneiss inclosed by massive granite, and granite exposed along the river separates the Hickory Creek ore from the nearest exposures of ore on the Bader tract.

No definite conclusion concerning the possibilities of the Bader tract can be offered. Compared with the great cropping and the abundant float at Iron Mountain the surface showings would seem to be unimportant. It is believed, however, that caution should be exercised in accepting an unfavorable point of view in cases of the sort here presented, since experience in other districts has shown that the importance of magnetite ore bodies in gneisses may be seriously misjudged from surface indications. It is suggested that the Bader tract is worthy of more extensive exploration than it has received up to the present time, and particularly that preliminary work in this direction should include a magnetic survey of the range which, as already stated, has a length of about 7,000 feet. It is thought that dip-needle observations might give indications of ore in the covered territory between the two ends of the Bader range.

The following are analyses of the ore from the Bader property:

Analyses of iron ore from the Bader property, Llano County, Tex.

	Metallic iron.	Phosphorus.	Silica.	Titanic acid.	Specific gravity.
1	64.150	0.014	72.80	0.385	4.577
2	52.550	.019	19.225	.310	....
3	65.800	.046	....	....	....

1. General sample of outcrop ore (Mr. McCreath). Report of E. V. D'Invilliers.
2. Sample representing 4 feet 10 inches of the mixed lens ore from the drill core on the Otto property. Report of E. V. D'Invilliers.
3. Bader tract. Report of E. V. D'Invilliers; by Rattle & Nye, of Cleveland, Ohio.

IRON MOUNTAIN.

By Sidney Paige.

The Iron Mountain prospect is located 12 miles northwest of the town of Llano and one mile northwest of Valley Spring post office. The property consists of 640 acres and is owned by Robert H. Downman, of New Orleans, La.

The ore body caps a low mound slightly above the elevation of the surrounding country, and trends about N. 60° W. in a gently curving line. The surface outcrop has a length of about 114 feet and a width of 22 feet at its center. It is slightly narrower at the northwest end and narrows down to about 6 feet at the southeast end. (See fig. 4.) A granite intrusion cuts across the mass at the northwest end, apparently cutting off the ore. Covered surface prevents observations on the southeast end.

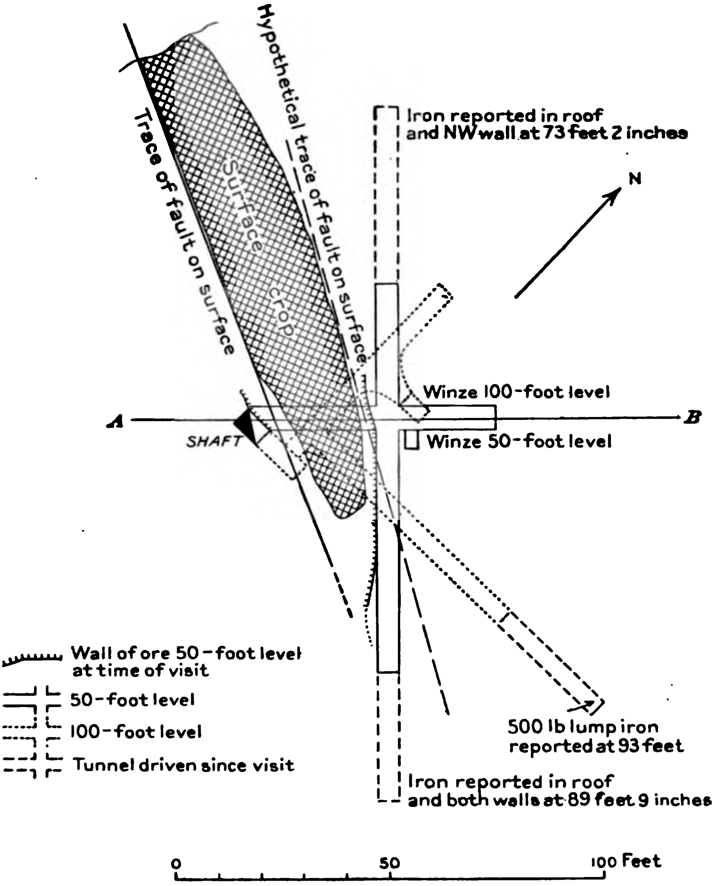
Hypothetical trace of fault on surface
Trace of fault on surface
Surface crop
Iron reported in roof and NW wall at 73 feet 2 inches
N
Winze 100-foot level
A
B
SHAFT
Winze 50-foot level
Wall of ore 50-foot level at time of visit
50-foot level
100-foot level
Tunnel driven since visit
500 lb lump iron reported at 93 feet
Iron reported in roof and both walls at 89 feet 9 inches
0
50
100 Feet

FIGURE 4.—Surface crop and underground workings at Iron Mountain prospect.

The ore body as revealed at the surface is a nearly vertical mass of very pure magnetite. Along its south side schists are exposed in several small cuts. They strike northwest with the ore, but in dip do not accord with the dip of the mass. (See figs. 4 and 5.) On the north side a gneissoid rock of granitic type forms the wall. It is believed to be intrusive into the ore, but is an older intrusion than that of the granite which cuts across the northwest end. Unfortunately the surface cover has rendered the exact surface relations of the ore body obscure; also the complex intrusion of granite into the schists, a condition described in an earlier part of the report, has at this locality obscured the original relations of the ore to the inclosing rock.

Both northwest and southeast of the ore body the surface is covered with soil and only occasional outcrops of weathered material may be seen. About 450 feet northwest a small outcrop of iron in schist was noted; granite, gneissoid granite, and schist are, however, evidently present in a complex mixture. Float ore can be found both northwest and southwest of the crop, but much of this in the near vicinity of the ore mass is evidently derived from it and has during erosion been carried to its present position. Some float ore derived from the overlying Cambrian sandstone and occasionally carrying fossils must not be confused with the magnetite float of the pre-Cambrian ores.

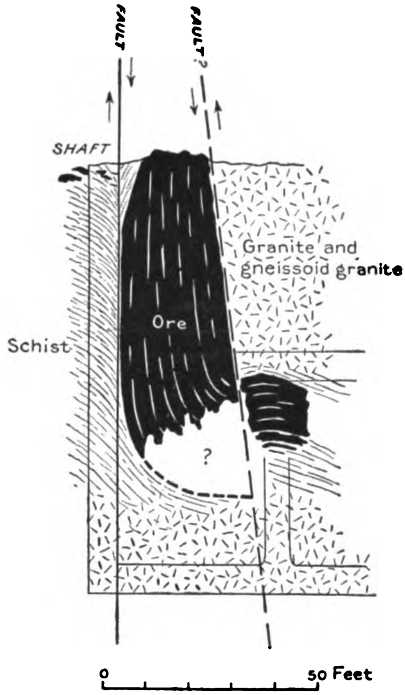

FIGURE 5.—Vertical section of ore body at Iron Mountain prospect.

A study of the plan and sections (figs. 4 and 5) will show clearly what is known of the structure of the body as revealed by developments. A shaft was sunk near the southwest wall of the ore body. A crosscut has been driven at the 50-foot level, showing 25 feet of solid ore. This crosscut was continued 54 feet. After passing through the 25 feet of ore a narrow mass of granitic schistose material was encountered, after which ore was again found. This second body was confined largely to the floor, and a winze was sunk in ore. (See fig. 5.)

On the 50-foot level two drifts were driven. (See fig. 4.) At the time of the writer's visit the northwest drift had been opened 30 feet, with no solid ore in any part of the working. Since that time the drift is reported to have been driven to 73 feet, with ore in the roof and northwest wall, at this point.

The southeast drift at the time of the writer's visit had been opened 60 feet, with solid ore on the south wall to a point 30 feet ± from the center of the crosscut. Since that time the drift is reported to have been driven to a point 89 feet 9 inches from the center of the crosscut, and to have had ore on the south wall the entire distance; and at that point is reported to have ore on both walls and in the roof.

At the 100-foot level crosscuts and drifts were run, as shown on the plan (fig. 4), but ore was not encountered under the vertical mass. The country rock is a mixture of schist and granite. A raise was made from the 100-foot level to connect with the winze, and revealed 16 feet of ore in a nearly flat-lying body of schist, grading downward into lean ore and granite. The schists containing the ore dipped at a low angle to the east.

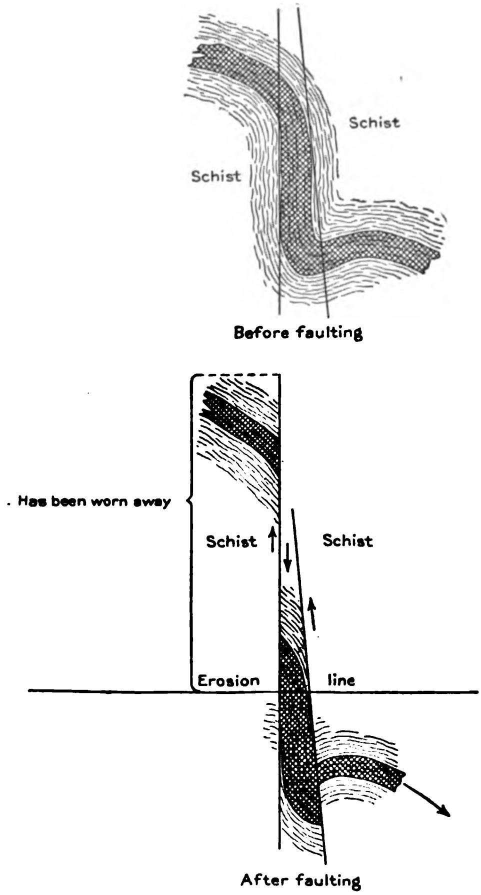

FIGURE 6.—Ideal section showing relation of faulting to folding and erosion.

The crosscut shown on the 100-foot level was driven 55 feet, but encountered no ore. At the time of the writer's visit the drift on the 100-foot level had been driven 62 feet, but no ore found. Since that time this drift is reported to have been driven to a point 93 feet from the center of the crosscut, and to have found at that point a lump of disconnected ore weighing about 500 pounds.

The relations described above may be hypothetically explained as follows: The vertical mass of iron ore is a layered body with the layering vertical. It is believed that formerly it occupied a position in accord with the schists, as does the mass exposed in the winze. Faulting is believed to have taken place on both south and north sides, though evidence for the latter is not as strong as for the former. (See fig. 5.) Several facts point to this conclusion. The schists on the south side dip sharply downward at their contact with the iron, suggesting fault drag, and a band of soft chlorite-like material about 2 inches wide is found at the contact. The drag was observed both at the surface and at the 50-foot level. The gouge material was not so well developed at this level. From the very fact also that the layering of the ores of the region has elsewhere been invariably parallel to the schistosity the discordance here is excellent evidence of faulting. At the 50-foot level on the north side, there is also a suggestion of faulting.

The direction and dip of these hypothetical faults may be somewhat different from those indicated by the plan and section, but the structural results of their presence are believed to be as presented.

The vertical iron mass, therefore, is on the downthrow side of both faults No. 1 and No. 2. The fault plane was for a distance parallel to the limb of a fold and accounts for the vertical position of the large iron mass and its peculiar relation to the flat iron bed. The difference in thickness between the flat bed and the vertical bed may be accounted for by supposing a certain amount of movement to have taken place in a horizontal direction, bringing a thinner portion of the layer against a thicker portion. Intrusion of granite probably preceded this faulting. There is some reason to believe, however, that the fault on the north side was accompanied or followed by granite intrusion. Figure 6 is an ideal sketch of the probable conditions before and after faulting, and figure 7 is a stereogram showing the relation which might exist if the north fault plane passed at an angle to the strike of the bed.

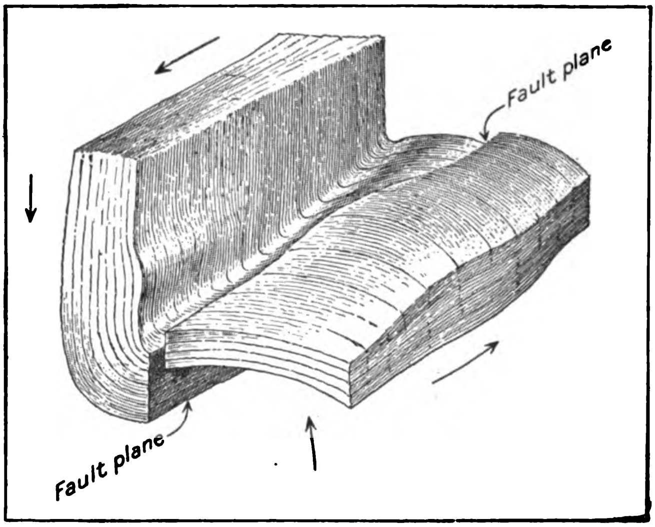

FIGURE 7.—Stereogram illustrating condition which would exist if the north fault passed vertically but at an angle to the strike of the fold.

Besides the development by shaft and tunnels above described the property has been prospected by several diamond-drill holes. They will be described in the order of their drilling.

The first hole, located 200 feet S. 57° W. of the shaft and inclined 37° toward it, was drilled to a depth of 169 feet. Two feet of ore was reported at 108 feet. This hole, to have reached the vertical plane of the ore body, should have been drilled 250 feet. It would have cut the plane at a depth of 150 feet.

The second hole, located 488 feet S. 72° E. from the northeast corner of the shaft, was drilled S. 4° W. at an angle of 43°. A foot of lean ore was struck at 18 feet. The drill jammed at 225 feet. Another hole at this same locality was drilled 290 feet S. 77° W. with a dip of 49°. Its record follows:

Record of hole drilled in Iron Mountain iron property, Llano County, Tex.

	Ft.	in.		Ft.	in.
Lean ore	14	11	to	16	..
Pink granite	16	..	to	25	..
Decomposed material	25	..	to	25	8
Granite	25	8	to	31	4
Black schist, little magnetite	31	4	to	35	8
Granite	35	8	to	198	1
Black schist and granite	198	1	to	199	..
Granite	199	..	to	215	5
Ore	215	5	to	216	8

Hole 253 feet deep on October 8, 1909, without commercial ore.

Next, a hole was drilled 500 feet northeast of the shaft. It was put down 500 feet. No ore was struck.

Then a hole was drilled on this same line, but only 216 feet from the shaft. It dipped 60° toward the shaft and was drilled to a depth of 606 feet. No ore was struck.

A hole approximately 1,400 feet northeast of the shaft and east of Johnson Creek was down 600 feet at the end of March, 1909, without striking commercial ore. It was drilled toward the shaft at an angle of 45°.

Analyses of ore from Iron Mountain, Llano County, Tex.

	Metallic iron.	Phosphorus.	Silica.	Specific gravity.
1	65.40	0.069	4.695	4.724
2	67.60	.093	4.690	4.677
3	65.45	.061	....	....
4	66.53	Not det.	....	....
5	64.90	Not det.	....	....
6	58.87	Not det.	....	....
7	61.45	Not det.	....	....
8	67.70	0.045	....	....
9	66.10	.034	....	....
10[a]	63.23	.008	4.70	....
11[b]	66.82	Trace.	4.65	....
12[c]	66.30	0.146	6.30	....

[a] Sulphur, trace. [b] Sulphur, 0.30. [c] Sulphur, 0.04.

1. General sample of surface ore. Private report of E. V. D'Invilliers.
2. Sample 125 pieces of ore at depth of 50 feet in shaft. Report of E. V. D'Invilliers.
3. Surface ore clippings large bowlders (sampled by representative of McCreath). Report of E. V. D'Invilliers.
4. Surface ore main exposure (sampled by representative of McCreath, 1889). Report of D'Invilliers.
5. From shaft 8 feet deep, south side main exposure. (McCreath.) Report of D'Invilliers.
6. From shaft 12 feet deep, north side of main exposure, lower 8 feet of ore. (McCreath.) Report of D'Invilliers.
7. 150 yards east of main exposure, from cut 4 feet deep. (McCreath.) Report of D'Invilliers.
8. From shaft at main exposure, ore from lower depth than 5 or 6, chiefly magnetic. Report of D'Invilliers.
9. Iron Mountain tract, sampled and analyzed by Rattle & Nye. Report of D'Invilliers.
10. 50-foot level, Iron Mountain mine; taken by Robert Linton, of Atwater, Linton & Atwater, mining engineers, for Johnston, Elliot & Co., of Dallas, Tex.
11. 50-foot level, Iron Mountain mine; taken by Robert Linton, for Johnston, Elliot & Co., of Dallas, Tex.
12. 7 feet of new ore on east wall of winze, 48-foot level, sampled by William B. Phillips, Rinaldo Williams, analytical chemist, Birmingham, Ala.

It would seem advisable to confine prospecting largely to the north side of the line of strike of the ore body. If it can be shown that the flat bed has considerable extension in a northwest-southeast direction and also on the dip, a large body of ore may be present. If underground work is to be continued it would seem advisable to make a raise from the end of the east drift on the 100-foot level, at the point where iron was struck, to discover the presence or absence of the bed. A magnetic survey of the territory adjacent to the ore body would be of value.

KEYSER-JONES TRACT.

By A. C. Spencer.

In Mason County, about 4½ miles south and somewhat west of Castell, magnetite float and ore outcrops occur at several places within the drainage basin of Keyser Creek, otherwise known as Old Place Creek. The relative locations are shown on the accompanying sketch map (fig. 8.) The most noteworthy showing is on a subdivision of the tract belonging to Judge J. H. Jones, of Mason. Here massive magnetite outcrops along a low hillock for a total distance of 75 feet, the maximum observed width of ore being about 4 feet. The ore is distinctly layered in its make-up and is rather siliceous. The trend of the cropping is about N. 45° W. No rocks are exposed within several hundred feet except at a point 100 feet southeast of the ore where micaceous gneiss was noted. About a quarter of a mile northwest along the general strike of the ore a low hill is formed of hornblende schist. If the outcrop at Iron Mountain be excepted, this is the largest surface showing of magnetic iron ore in the Llano district. At present, however, there would be no adequate inducement to warrant the expense of drilling at this point, though in the future such exploration might be advisable.

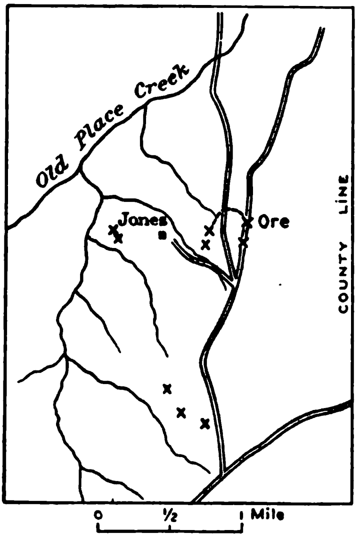

Figure 8.—Magnetite prospects on Keyser-Jones tract, southwest of Castell.

A second fairly good showing of magnetite may be seen on a hilltop somewhat less than half a mile east and a little south of Jones's house above the tank (stock reservoir). This ore is accompanied by red-weathering gneiss or schist, a curving band of which may be traced to the northeast and east across the two roads shown on the sketch map. Magnetite float may be found from place to place along this red band, but one does not gain the impression that excavation is likely to reveal any body of ore.

A mile or more farther south minor amounts of magnetite may be found in association with highly metamorphic schists, and in this case outcrops are adequate for a decision that no deposits of economic importance are to be expected. On the whole the possibilities of the tract seem to depend upon the Jones outcrop.

GOODWIN PROSPECT.

By SIDNEY PAIGE.

About 2½ miles S. 55° W. of Babyhead post office, small outcrops of iron ore may be seen on Mr. Goodwin's place. The rocks are believed to belong to the lighter (lower) gneiss and schist series (Valley Spring gneiss), and are, as is almost invariably the case, more or less intruded by granite.

A short distance north of Mr. Goodwin's house a small trench reveals a foot or two of lean hematite ore banded with quartz and feldspar, the latter minerals forming a very fine sugar-grained aggregate. The individual thin iron layers swell and pinch in an irregular manner. What appears to be secondary quartz is introduced in bands along the schistosity in considerable abundance. The hematite is feebly magnetic, and octahedral faces can be detected among the crystals. The mineral is probably martite, a pseudomorph of magnetite.

Farther west over the ridge may be seen white schists of very even, fine, sugar-grained texture, carrying finely disseminated hematite in minute grains. Abundant orthoclase feldspar, with quartz and muscovite, make up the rock, which is believed to be a metamorphic sediment.

About 1,000 feet S. 10° E. from the house a shallow pit in the schists reveals a small bed of magnetite lying nearly flat and striking nearly east and west. About 9 or 10 inches of ore is exposed for 50 feet. The dip is to the south, more pronouncedly so at the west end. Considerable garnet and abundant quartz with some pyrite are the gangue minerals.

Less than 1,000 feet west of the locality and S. 37° W. from the house just described, a small pit shows an apparently vertical bed of magnetite and quartz with 1 or 2 feet of lean ore. This deposit can be traced for 100 feet in the trend of the ridge. Locally there is an indication of about 5 feet of ore. The north end of the outcrop is apparently cut off by a swing in the beds of pink schist.

No encouragement can be given that these deposits have any commercial value.

PARKHILL PROSPECT.

By Sidney Paige.

About 1 mile east by south of the summit of Horse Mountain a small quantity of ore may be seen about 2,300 feet north of and between the forks of two creeks. The bed strikes N. 55° W., dips 20° S., and is about 2 feet thick. The magnetite is admixed with quartz and red feldspar, and the pit reveals decided irregularity in thickness. The deposit does not seem worthy of further prospecting at the present time.

About 1 mile northwest of Miller Mountain and east of the main north and south Babyhead road, a small trench shows a foot or a foot and a half of lean ore in schist. The country rock trends about N. 30° W. and dips south. This opening and another a short distance northwest of it do not offer any inducement to further prospecting.

IRON DEPOSITS NEAR CASTELL.

By A. C. Spencer.

Castell post office is situated on Llano River 18 miles west of Llano. North of the river within the radius of a few miles there are showings of iron ore at several places which may be described in two groups—the Deep Creek deposits and the Elm Creek deposits. The ores of the Deep Creek and Elm Creek drainage basins are regarded as of no probable value, because the deposits, though extensive, are both lean and thin. At the same time by way of caution against absolute disparagement it is to be noted that such development work as has been done is negligible, so that the impressions gained by the geologists have been derived from very imperfect surface showings. With due allowance made for this condition, the opinion may be expressed that although future work may lead to the discovery of ore masses of sufficiently high grade to warrant mining operations, such ore bodies will not prove to be of large size, so that it can not be expected that any large mines will ever be developed in the combined field of Deep and Elm creeks.

DEEP CREEK ORES.

Deep Creek (fig. 9) joins Llano River about 1½ miles above the Castell ford. From the river the creek valley extends a mile west to an elbow, above which it has a general north-south course for somewhat more than a mile before turning again to the west about one-fourth mile north of the Mason stage road.

The magnetite deposits occur in the Deep Creek valley near the lower elbow and again north of the Mason road.

The magnetite showings near the elbow of Deep Creek are disposed along a line about a mile in length. Downstream from the bend the presence of a little ore is noted on the north bank of the creek, and toward the southeast heavy float is noted at two points. At these localities the ore is massive and nearly pure, the only minerals present besides magnetite being a little feldspar and mica. The manner of occurrence is not evident, but the three localities lie along a line trending northwest and crossing the creek both below and above the elbow. Opposite the elbow none is noted, but west of the creek it again appears and abundant float may be traced along the hill slope north of a small drain. About 1,800 feet above the mouth of this drain the line of the ore crosses the shallow valley and turns back upon itself. The hook-shaped outcrop may be taken as evidence that the ore occurs as a conformable layer in the local schists and that the rocks are here thrown into a low arch or anticline.

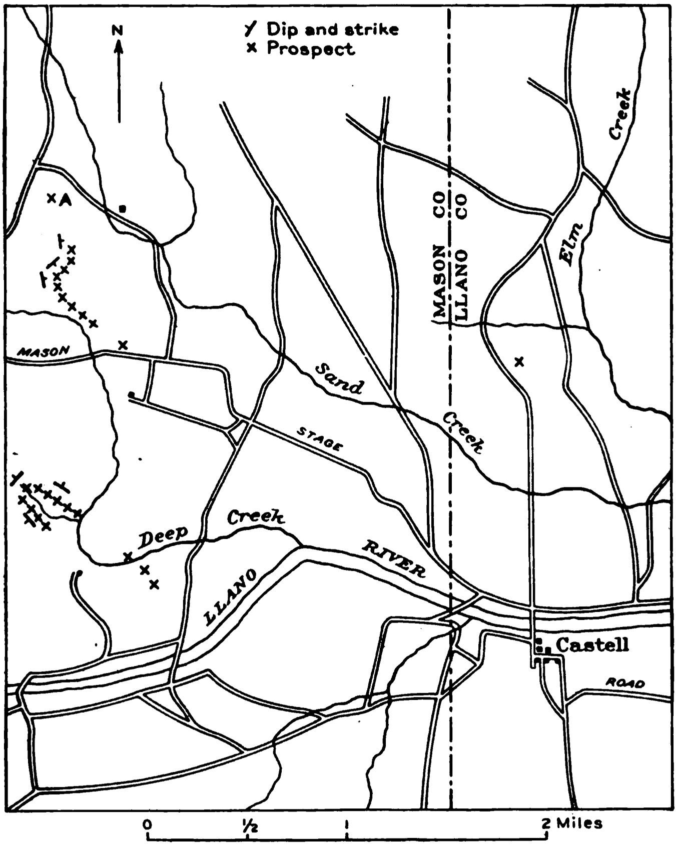

FIGURE 9.—Distribution of magnetite near Deep Creek.

A few outcrops of feldspathic schist in the neighborhood exhibit strikes and dips which bear out this impression of structure.

Though the exposures of ore are very inadequate, they serve to convey the impression that the iron mineral may be distributed through 3 or 4 feet of rock, and that the reef is made up of layers of rock and ore from 6 to 10 inches thick. Some of the component layers are high-grade ore; others are platy aggregates of magnetite and siliceous minerals; still others carry but little iron.

North of the Mason road, east and north of Deep Creek, magnetite is found at several points. A short distance north of the road a few isolated fragments of good ore were noted. Then a quarter of a mile or so to the northwest there has been some prospecting. Natural outcrops, shallow pits, and float lead to the recognition of a curving magnetite range perhaps half a mile in length (fig. 9). There are evidently two parallel reefs along part of the range which are estimated to be less than 20 feet apart, measured across the layering. The curving outcrop and observed dips show that the ore and associated schists are gently folded. The dips are low to the east, or, locally at the turn, approximately south.

The ore appears to be rather lean, much of it showing garnet mixed with magnetite. Specimens were seen which are composed of alternate thin layers of fairly clean magnetite and of quartz. The garnet-bearing reefs vary in thickness from 18 inches to 3 feet.

The ore reefs are by no means continuous along the strike. Part, but certainly not all, of the observed discontinuity is due to the presence of irregular intrusive masses of granite, both fine and coarse grained varieties being present.

North of the occurrences mentioned in the foregoing paragraph, at the locality marked A on the sketch map, figure 9, there is a rather noteworthy showing of magnetite float. In addition to good-sized chunks of pure ore there is an interesting exhibition of coarsely crystalline material composed of quartz, pink feldspar, and magnetite in various proportions. This material is not exposed in place, but it has every appearance of being pegmatite (extremely coarse granite) of very siliceous and ferruginous composition, and is therefore believed to be intrusive in its nature. Magnetite-bearing pegmatites were noted in small amounts at many places in the Llano district, but no other instance of any great amount of the mineral in this association was seen. Though the ore at this particular place is regarded as almost certainly of igneous origin, it is not regarded as possible to use this conclusion in any definite way in working out the general origin of the iron ores of the district.

If the layered ores of Deep Creek valley are not merely ferruginous strata which have suffered simple metamorphism in company with sedimentary beds originally associated with them, as suggested by Mr. Paige elsewhere in this report, they were formed by some process the nature of which can not be stated—some process, as yet unrecognized, involving secondary rather than primary or original segregation.

ELM CREEK ORES.

The distribution of magnetite showings northeast and east of Castell is given on the sketch map (fig. 10). It should be noted that the area shown on this map overlaps that of the Deep Creek sketch map (fig. 9).

Between the southward-flowing portion of Elm Creek and the next considerable valley to the east the land rises to form a rolling plateau. Along the west edge of this plateau, just at the break to the Elm Creek slope, or locally somewhat down this slope, an iron-bearing reef may be followed by means of float and occasional outcrops for a distance of 1½ miles. The trend of this reef is nearly north-south, the north end (in the form of a hook) being situated 1 mile northeast of the Lang house. Though there is no difficulty in following the lead by means of the surface showings, the ore is seen not to be really continuous, being interlayered with the associated feldspathic gneisses. Locally there are evidences of two ore layers, neither one of which can be more than 2 feet thick. Dips are uniformly low to the east. All of the ore

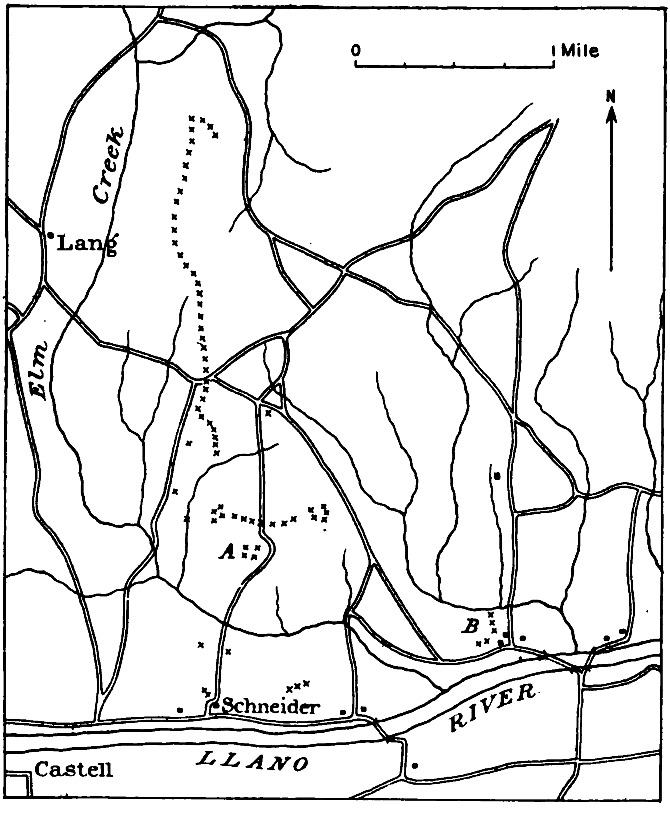

FIGURE 10.—Distribution of magnetite near Elm Creek, northeast of Castell. *A*, Area shown in figure 11; *B*, area shown in figure 12.

is lean in appearance, and scarcely any of it would analyze above 30 per cent of iron.

The south end of this line of croppings is north of a small drain in the northeast corner of Dr. Donges's pasture, and for a distance of about 1,000 feet to the south along this trend there are no signs of magnetite. West of the trend, however, minor amounts of float were noted at two points, and a 6-inch seam of ore outcrops in the stream bank at a point indicated on the sketch map (fig. 10). In the vicinity of this stream the rocks appear to be greatly disturbed, as there are great variations in strikes and dips from place to place. At the 6-inch capping noted above the dip is about 45° NNE.

Directly east of the exposure last mentioned and west of the Donges-Ebers property line, on the edge of the plateau, a flat-lying layer of lean ore about 2 feet thick has been stripped of its original cover over an area of perhaps 250 square feet. This flat constitutes the western limit of a line of outcrops extending in an easterly direction along the southern break of the plateau for a distance of approximately 3,000 feet. The western exposure lies due south of the termination of the north-south line of croppings already described, the barren interval between being about 1,200 feet.

Locally along this east-west trend there are indications of magnetite in two layers, perhaps 20 feet apart, but usually there is only one layer. At the east end of the line of outcrops the ore layer is complexly folded and also disrupted by granite intrusions. Along the cropping the dip is to the north at a very low angle.

Wherever exposed, the ore is lean in appearance, because of the amount of quartz and potash feldspar which it contains. Its thickness was nowhere observed to be greater than 2 feet, and nearly everywhere it is less than 18 inches. The associated rocks are feldspar gneisses and granite. At many points thin sill-like masses of coarse granite (pegmatite) lie under the ore layer, but no genetic relation may be made out between this rock and the magnetite.

Four samples collected to represent the ore of this eastward-trending outcrop may be taken as typical of the ores of the Elm Creek occurrences, since there is very close resemblance in the material observed in all of the several localities. Samples 1 to 3 came from near the east end of the line of outcrops and sample 4 from a point near where the reef crosses the wagon track.

Analyses of Elm Creek iron ores, Llano County, Tex.

[R. C. Wells, analyst, United States Geological Survey.]

	1.	2.	3.	4.
Fe	25.68	26.04	14.60	24.70
SiO_2	54.56	52.23	62.53	55.36
Mn	Trace.	.06	None.	Trace.
P	.04	.05	.01	.05
S	.06	.10	.04	.07
TiO_2	.10	.20	.11	.10

In the northern part of Christian Schneider's pasture, about a quarter of a mile south of the east-west ore belt described above, similar lean material occurs within an area about half an acre in extent. The ore evidently occurs as a layered deposit thrown into shallow folds, though the rock layers are not exposed with sufficient completeness to clearly reveal the structural details (figs. 10 and 11). Considerable intrusive granite is noted within the area, including the different outcrops of ore.

The thickness of ore observed varies from 15 inches to 3 feet.

South of Elm Creek ore is to be observed at four points. Near the north side of Schneider's horse pasture is a single outcrop of an ore layer 2 feet thick. East of this a small amount of float is encountered along the wagon track, and as the local trends are east and west it may be suggested that prospecting would reveal a more or less continuous lead between these two points. A short distance north of the Schneider house the presence of float suggests the existence of a nearly east and west trending ore layer extending west of the wagon track for perhaps 200 feet. The fourth locality south of Elm Creek is on the hilltop between the creek and the river, partly within the Schneider tract, but extending across the east boundary line. The rocks are layered feldspathic schists, weathering of which produces a very red soil. The ore, which is interlayered with the schist, may be seen to have a local

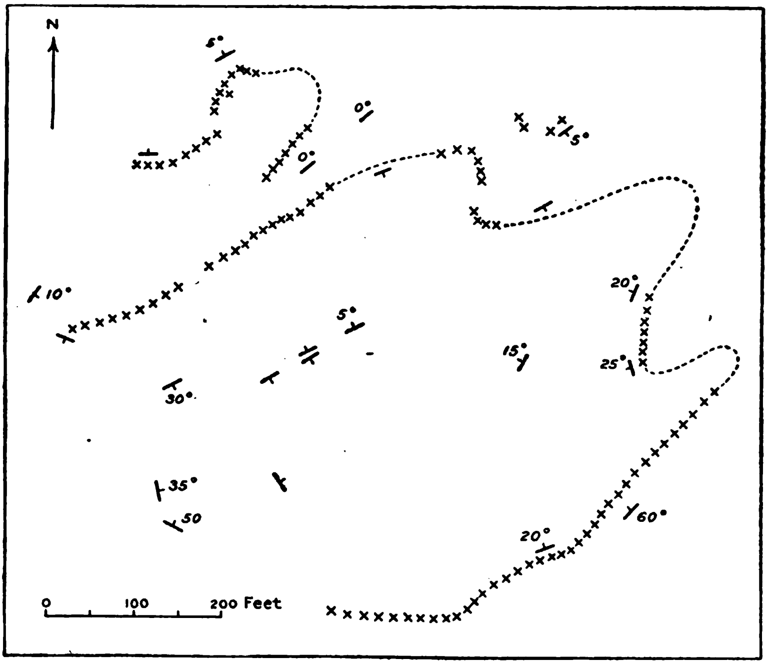

FIGURE 11.—Distribution of magnetite showings in northern part of Schneider's pasture (*A*, fig. 10).

thickness of 18 inches, though it is thinner in places. A sample of the best-looking material in sight gave the following analysis:

Analysis of Elm Creek iron ore, Llano County, Tex.

Iron	35.40
Silica	34.68
Manganese	Trace.
Phosphorus	.03
Sulphur	.04
Titanium oxide	.15

The ore layer may be traced by means of outcrops and float for a distance of approximately 600 feet along a general northeast course, but the stronger showings are confined to the southwest part of the area of outcrop. Here the ore and the associated rocks are evidently folded to a considerable degree, and possibly have been duplicated by dislocation.

About 2 miles east of Castell and 1 mile east of the locality described in the foregoing paragraph magnetite is found in two places about 1,000 feet apart. (See figs. 10 and 12.)

On the north the ore may be traced along a low ridge in a southerly direction for a distance of 825 feet. The reef as seen in natural exposures, no trenching having been done, may have a maximum thickness somewhat in excess of 6 feet, though throughout much of its length it is almost certainly thinner. No sample was analyzed, but from the general nature of the material it can hardly carry above 35 to 40 per cent of iron. The better portions of the ore closely resemble lean portions of the Iron Mountain ore. The reef is cut across by two granite dikes 30 and 50 feet wide. The dip of the ore was not satisfactorily determined, though it is probably low toward the east.

South from the last outcrop is a belt of red soil within which, at a distance of 930 feet, strong magnetite float again appears. Near by is an outcrop of lean ore dipping about 10° E. From this outcrop there are almost continuous showings along a curving zone for a distance of 400 feet or more. Beyond where the zone turns from south to west the ore lies nearly flat and is obscurely exposed for a width of about 50 feet. The material is of very lean appearance. It can hardly be more than 3 feet thick and is probably thinner.

LIVELY TRACT.

By A. C. Spencer.

The Lively property lies somewhat more than 1 mile southeast of Iron Mountain and three-fourths of a mile southwest of Valley Spring. There has been no development, and the showing is confined to magnetite float in the wagon road northeast of Johnson Creek. The position of this locality is near a line joining the ore at

Iron Mountain to the northwest and the Becton ore 4 miles to the southeast. Although the three localities are thus in alignment there is no adequate basis for the suggestion of any connection between the several deposits or for any expectation that intermediate deposits are likely to be discovered.

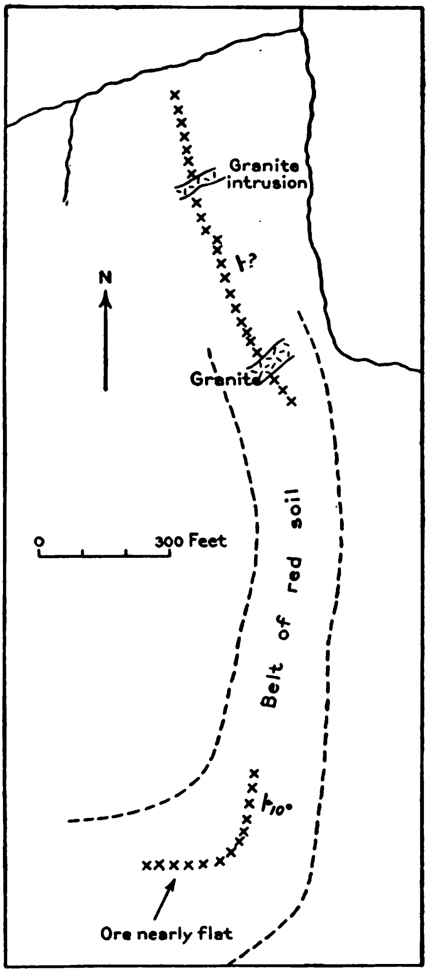

FIGURE 12.—Distribution of magnetite 2 miles east of Castell (*B*, fig. 10).

Between the Lively ore and Iron Mountain the ancient gneisses are buried beneath Cambrian sandstone, the northern edge of an east-west band of this rock being situated about 1,000 feet southeast of the Iron Mountain shaft.

SECTION THIRTEEN AND VICINITY.

By A. C. SPENCER.

The tract of 640 acres known as H. and G. N. Section Thirteen lies about 4 miles south of the Iron Mountain property, on the southwest side of San Fernando Creek, at the mouth of Willow Creek. Magnetite has been found at several places on this tract and at several localities in the neighborhood on both sides of San Fernando Creek. The distribution of these showings is indicated on the accompanying sketch map (fig. 13).

There has been some prospecting south of the east-west road leading to Epperson's house, about 2 miles east of San Fernando Creek, and east of Epperson's boundary line. The old trenches are so badly filled that they afford no indication of what may have been found, and all that can be seen at present is rather sparse float of magnetite in small pieces. This float may be found at intervals for about 400 feet along a line trending a little west of north.

Three-quarters of a mile southeast of Epperson's house, where the road crosses a small ravine, heavy float of magnetite in solid chunks is noted. This float may be traced to a small outcrop near by, but nothing may be said of the prospects of this occurrence until some development work has been done. The ore closely resembles the material on the surface at the Iron Mountain mine.

About 1½ miles southwest of the locality mentioned in the foregoing paragraph and half a mile south of the Otto house chunks of solid magnetite a pound or more in weight were noted in the wash of a small drain. Though hornblende gneisses outcrop in the vicinity, the ground is largely covered by rock waste, so that no suggestion is warranted as to where this ore would be found in place. East and south of this locality granite is very much in evidence, though as noted in the description of the Bader tract, slivers of gneiss are included in the area northwest of the Bader workings. Careful search in this interval of 2 miles failed to reveal any iron-ore float.

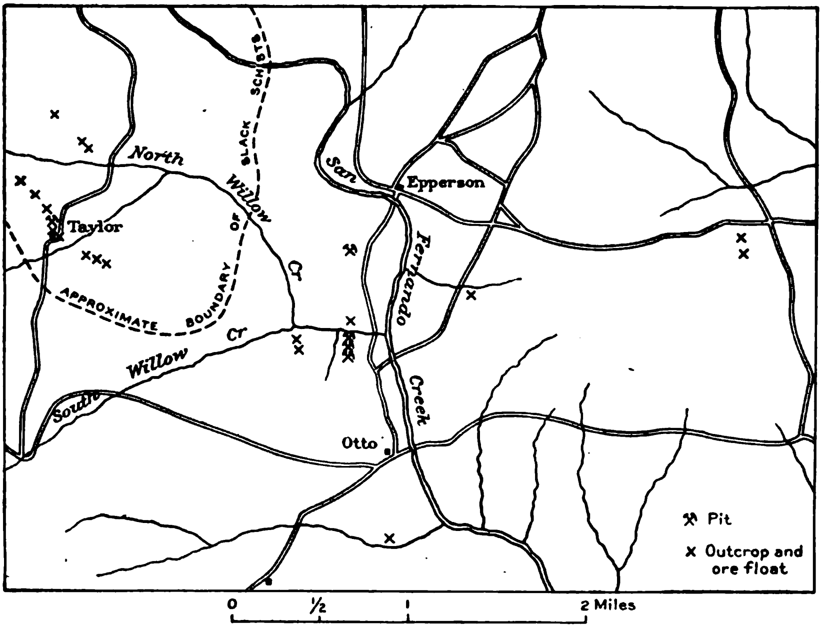

FIGURE 13.—Magnetite prospects in H. & G. N. Section Thirteen.

West of San Fernando, in section 13, magnetite has been discovered at three localities, the relative positions of which are roughly indicated on the sketch map. The presence of float ore led to the digging of several pits, some of which are still in such condition as to show that the magnetite occurs in gneiss. The ore and the country rock are distinctly layered, with dips toward the east. A study of the southeasterly pits suggests the presence of at least two leads somewhat less than 100 feet apart, trending a few points east of north.

Fairly abundant float may be found for a distance of about 600 feet along this zone, and three pits have been dug. On the south an opening 8 feet deep has exposed 1 foot of solid ore dipping east with a granite footwall. At a depth of 3 feet the granite cuts off the ore along a flat contact.

A hole 6 feet deep situated somewhat east of the last-mentioned shows 7 feet of layered material-carrying ore. The strike is N. 10° E. and the dip about 25° E. The lead is complex, being made up of two fairly solid layers of ore separated by light-colored granitic rock carrying a minor amount of magnetite. The upper ore layer is from 10 to 14 inches thick and the lower layer about 2 feet thick. The immediate footwall is whitish granite gneiss about 1 foot thick, and below this is hornblende gneiss carrying considerable magnetite. (See fig. 14.) A short distance east of this pit is an exposure of hornblende gneiss carrying garnet and epidote.

The next opening to the north is 4 feet deep. Here the rock layers exhibit a low dip to the east. At the bottom is hornblende gneiss, then a layer of white gneiss varying from 1 foot to 18 inches in thickness and carrying irregular masses of ore, one of which was noted to have a diameter of 10 inches; next above this layer comes 8 inches of hornblende rock, and this is followed by gneissoid granite. Magnetite is disseminated through the hornblende rock in fine grains, but in the white gneiss the iron mineral is coarsely granular. This occurrence strongly suggests that the ore was generated in a layer of intrusive material, or, more definitely stated, the impression is given that this ore is of igneous origin. The reader will, however, note that the general features of the Llano ores have not been interpreted as particularly favoring a hypothesis of igneous origin.

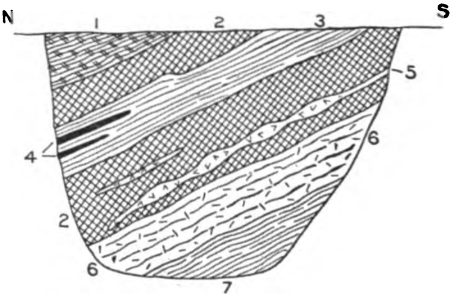

FIGURE 14.—Relation of ore layers in pit south of Willow Creek in section 13. 1, Feldspar-magnetite gneiss; 2, ore; 3, gneiss; 4, magnetite; 5, pegmatite; 6, granite gneiss; 7, hornblende gneiss.

About 90 feet west of the 4-foot pit a shallow excavation shows a 10-inch layer of magnetite embedded in white gneiss. This ore contains flakes of mica and closely resembles ore from the Deep Creek locality described on a subsequent page.

The surface indications just south of Willow Creek forks are rather meager, as very little work has been done.

North of Willow Creek, on the top of the hill, is a single pit 9 feet deep which affords a good exposure of magnetite-bearing gneiss. The strike of the layering is N. 35° W. and the average dip about 50° NE. Approximately 8 feet of rock is exposed and about half its bulk appears to be magnetite. The casing material of the lead is mica-bearing granite gneiss of the same general appearance as that at the Iron Mountain mine. The general character of the ore is like that taken from the Bader incline, but the rock layers exhibit more irregularity and are more contorted than at the Bader locality. Layers of solid magnetite are in no place more than 8 inches thick, but a 30-inch layer of rock is estimated to be three-fourths magnetite. Most of the magnetite is fine grained, but here and there strings and bunches of coarse-grained mineral are noted. As represented in the sketch given as figure 15, the immediate hanging wall is feldspathic gneiss carrying mica and magnetite; the footwall is light-hued granitic rock nearly free from dark minerals. Immediately under the contorted layer of heavy ore represented on the left side of the sketch is a layer of granitic material with ore irregularly distributed through it. This portion of the lead presents the appearance of an injection which has been forced into the ore-bearing rock; if it is actually invading material, fragments of ore torn from the walls have been drawn out and incorporated in its mass.

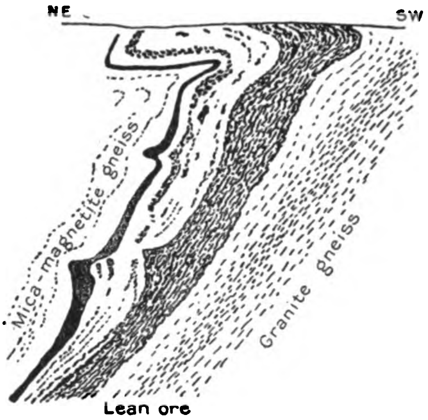

FIGURE 15.—Sketch of 8-foot ore surface in magnetite gneiss.

The immediate environs of the pit exhibit no exposures, bedrock being covered by an apparently deep mantle of residual sand. Float ore is not noted along the strike of the lead.

Though there is some doubt concerning the proper classification of the rocks with which the ore in section 13 is associated, they have been mapped as belonging to the lower (lighter) series of schists (Valley Spring gneiss). Another possibility is that they represent the dark schists very extensively injected by granitic material.

West of section 13, in the drainage basin of the north fork of Willow Creek, iron ore has been found at several points, and here the rocks are definitely recognized as belonging to the dark series (Packsaddle schist) with associated limestones. Aside from the Olive mine, this is the only occurrence of really noteworthy segregations of magnetite which can be unequivocally assigned to this set of rocks.

The approximate boundary of the dark schist area is shown on the sketch map (fig. 13, p. 50). It is to be noted that the principal showings of ore are aligned parallel to this boundary as it is represented upon the map. The ore layers dip toward the interior of the dark schist area.

Southeast of the main fork of North Willow Creek ore float a few shallow openings show the presence of magnetite at various points along a curving line about 5,000 feet in length and at a few isolated points north and east of this line. The ore material exhibits a somewhat siliceous aspect, and all of it is distinctly layered. Near the main creek and again southeast of the tributary which passes the Taylor house, fragments of ore lying on the surface are made up of alternating layers of dense, fine-grained magnetite and of quartz, the layers varying in thickness from one-half inch to 2 inches. It seems that there are at least two distinct layers of this material in the northern portion of the range. Their maximum thickness appears to be less than 2 feet.

In the central part of the range more massive ore is exposed, and at a pit north of the Taylor house a 17-foot section of the ore is exposed. The ore is a mixture of magnetite and hornblende, and it is judged from what may be seen on the surface that a layer of similar material at no place less than 4 feet thick has an extent along the strike of about 600 feet. Near the house the ore mass is probably more than 20 feet wide.

A sample representing the entire 17 feet of ore exposed in the pit mentioned above gave the following analysis:

Analysis of iron ore from sec. 18, Llano County, Tex.

[R. C. Wells, analyst, U. S. Geol. Survey.]

Fe	35.87
SiO_2	34.57
Mn	1.05
P	.07
S	.04
TiO_2	.15

From the surface indications it is believed that this body of iron-bearing material may be expected to hold its size and character to a depth of several hundred feet along the dip. Only the lean nature of the material stands in the way of the suggestion that the lead is worthy of detailed exploration; but it seems hardly likely that any but high-grade ores will warrant the railroad construction required for transportation. Enrichment of this material by means of magnetic concentrators would appear to be feasible from the technical standpoint, but at present certainly not practically advisable.

Three or four minor outcrops of magnetite north of the north fork of the creek appear to be of no particular interest. They exhibit the same general trend as the main range, but it is not possible to correlate them in any way with the more prominent line of outcrops.

From the structural features of the ore range which has been described it appears to be obvious that the ore is developed along a definite horizon in a set of sedimentary rocks; any additional characteristics which have been observed as bearing on the origin of the ores will be discussed later in more detail.

RILEY MOUNTAIN.

By A. C. Spencer.

Prospecting has been carried on at several places along the east base of Riley Mountain between Click post office and Honey Creek, and also north of Honey Creek. (See fig. 16.) Most of the surface showings are pyrite gossans, though one, situated 1 mile north of Click, is magnetite.

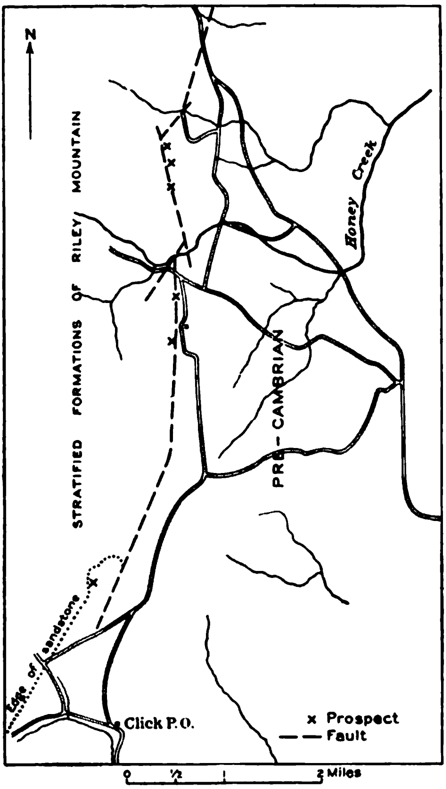

Figure 16.—Map showing location of pyrite deposits north of Click post office and their relations to faults.

The pyrite bodies were under exploration during the summer of 1909, so that a fair opportunity of studying their features was afforded.

Development work on the Roberts place, south of Honey Creek, shows that the iron cap gives place to the original sulphide within 20 feet of the surface. At this place the sulphur-bearing material is arsenical iron pyrites. The mass has been shown to have a width of 15 feet and has been exposed (June, 1909) for a length of 25 feet. Adjacent to the Roberts pit (an incline) float may be traced for a distance of 500 feet along the lower slope of the mountain; somewhat farther north are other showings along the same general trend. The deposit is in limestone adjacent to a very strong fault which brings the stratified limestones of Riley Mountain against very much older crystalline schists on the east. The ore is not on the fault but about 50 feet west of it. It appears to have been deposited by replacement of the limestone and to follow the bedding of the rock which dips toward the west and away from the fault. The rocks are poorly exposed, but there is reason for believing that the rocks are greatly broken adjacent to the main line of faulting, so that it may be that the ore follows a zone of shattering rather than a layer of the limestone.

The conditions of structure suggest that the deposits should exhibit considerable continuity in depth, but developments are not adequate to show whether or not such is the case. The fault adjacent to which the pyrite ore occurs is traceable for several miles southward from Honey Creek, though evidences of iron capping were not recognized far beyond the Roberts opening.

About a mile north of Honey Creek, on the Bedford tract, is a shaft said to have been opened prior to the settlement of the district. Near by a shaft was sunk in 1909 to a depth of 70 feet. Here there is evidently a crush zone adjacent to a strong fault. The lead which has been opened by the shaft appears to be a filling of crushed material along a fault which brings together cherty limestone on the west and red sandstone on the east. The material of the lead is red iron oxide and coarsely crystalline calcite. Brown iron ore in the crystalline form of pyrite (that is to say, limonite pseudomorphs after pyrite) was observed, but part of the red oxide may have been derived from the alteration of carbonate of iron. East of the shaft there is a band of red sandstone 60 feet wide, then another fault bringing up the crystalline schists.

It is evident that the showings of iron gossan in the neighborhood of Honey Creek can have no value as a source of iron ore. Whether or not the deposits from which the gossan has been derived will ever be worked as a source of sulphur or arsenic can not be foreseen. Parties engaged in exploring the deposits state that the sulphide shows no valuable quantities of gold or silver.

West of Click post office the basal sandstone of the sedimentary series of Riley Mountain laps over the ancient crystalline schists. The line between the sandstones and the schists trends northeast and finally curves out toward the east to meet the fault along the east face of Riley Mountain. Along this boundary, about 1½ miles north of Click, abundant float of very pure magnetite is noted in a small branch west of the Wilson house. This float is readily traced to its source at the sandstone overlap. Part of the loose ore has undoubtedly been derived from the lowest part of the sandstone, as fragments of magnetite may be seen in this rock. Another part may have been derived directly from ore occurring in the schist, though the position of a lead has not been discovered. On the whole it seems probable that all of the material is really débris from the sandstone and that the bedrock deposit does not come to the present surface because it is capped over by the sandstone.

A few hundred feet southeast of the point where the sandstone containing magnetite fragments is exposed there is a shaft said to have been opened in search for copper ore. Though the material taken from this shaft does show the presence of copper minerals, there is nothing to encourage further work.

ORIGIN OF THE IRON ORES.

By Sidney Paige.

POSSIBLE HYPOTHESES.

Three possibilities have been recognized in an endeavor to arrive at a definite conclusion concerning the origin of the iron ores described in this report. They are as follows:

1. That the beds represent igneous segregations from a granitic magma and owe their tabular form to flowage under pressure; that is, they represent granitic magmas impressed with a foliate structure.
2. That the ores are replacements of sedimentary beds, either before or during metamorphism, due to emanations from a granitic magma.
3. That the ores represent metamorphosed iron-bearing sediments.

Since the arguments presented to substantiate the last mode of origin will necessarily involve arguments against the first and second, a separate treatment of those hypotheses is not necessary.

A modification of the third hypothesis would recognize the possibility that iron had been introduced into unmetamorphosed beds, which were subsequently metamorphosed.

The writer alone is responsible for the views here set forth and realizes the difficulty of arriving at a definite conclusion. The value of various classes of evidence varies with the problem in hand; only by a careful weighing of these values can a legitimate conclusion be reached; and speculation, unless demanded, should be relegated to its proper place. The writer will endeavor to distinguish between considerations that are speculative and those that are not.

The considerations presented will fall under the following heads:

(1) The general distribution of iron throughout geologic formations and the character of the accompanying beds; (2) the geologic relations of the iron ores; (3) the characteristics of the ores having a bearing on origin; (4) the relations of the igneous rocks of the region; (5) the chemical factors involved; (6) comparison with other regions.

GENERAL DISTRIBUTION OF IRON THROUGHOUT GEOLOGIC FORMATIONS AND THE CHARACTER OF THE ACCOMPANYING BEDS.

The Upper Cambrian sandstones and limy sandstones of Llano County, Tex., carry disseminated iron oxides—hematite and limonite. Locally there is a fairly high content of iron (though not from a commercial standpoint) and the iron-bearing horizon is persistent. Within this series are also beds bearing glauconite—hydrous potassium-iron silicate.

The specular hematite ores of Virginia and other Appalachian States occur in rocks of Cambrian age.

In the lower Silurian of central Bohemia, composed of quartzites associated with slates, graywacke, conglomerates, diabases, amygdaloids, and diabase tuffs, occur hematite and carbonate iron ores, the former in diabase tuffs, the latter in quartzites between graywacke[a] slates.

The Clinton ores of the Silurian are interbedded with clay shales, sandstones, and impure limestones.

Iron ore accompanies the "Coal Measures" of the Carboniferous on the Continent, in England, and in the United States.

The ores of the northern Alps (probably Permian) are in a so-called graywacke zone.

The minette ore beds of the Dogger formation are found in the Jurassic of Alsace-Lorraine in beds of a limy and sandy composition. Green iron silicates are noted.

In the Eocene of Bavaria oolitic ores occur. Glauconite and quartz sand are noted.

Finally, deep-sea investigations have proved the very wide distribution of highly ferruginous sediment.

These facts point at once to two conclusions—that the presence of iron ore is to be expected in the sedimentary record of all periods, and that this means of accumulation, that is, sedimentation, illustrates at least one potent factor in ore segregation.

The nature of the metamorphic rocks found in the pre-Cambrian complex leaves little room for belief that the processes of sedimentation during pre-Cambrian time could have been appreciably different from those which proceeded during the more easily read periods which followed. It is therefore natural that bedded iron ores derived from primary sedimentary deposits should be present in the pre-Cambrian complex.

J. J. Sederholm[b] has described in great detail the manner in which granites have intruded the schist-gneiss series of Finland, and a remarkable similarity may be noted between the processes at work there and those observed in the Llano region; but he makes no note of iron ore. It seems to the writer that this absence of iron is more than a mere accident which might be explained away by referring to the vagaries of granite intrusions (introducing iron in one locality and not in another). It is more logical to believe that the reason for the absence of iron ores in the above-cited locality lies in the fact that that portion of the schist-gneiss series which is there (in Finland) exposed to observation represents beds barren of sedimentary iron deposits.

GEOLOGIC RELATIONS OF THE IRON ORES.

So far as could be observed the iron ores are an integral part of the Llano series and exhibit much the same relationship to the other members as do the limestones and the graphite schists. They are tabular in form, can be traced along the strike where not covered or interrupted by granite, follow all the convolutions of the rocks which inclose them, vary in thickness and in iron content as do graphite-bearing strata in carbon, and locally grade into the surrounding country rock by a gradual decrease of iron. They are layered deposits, even in the locality of their heaviest development.

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[a] "Sandstone-like rocks which in addition to the quartz and feldspar of an arkose contain rounded or angular bits of other rock. Some varieties * * * composed largely of feldspar may be difficult in the hand specimen to distinguish from some felsite."—Pirsson, L. V., Rocks and rock minerals, p. 326.

[b] Om Granit och Gneis: Bull. Comm. géol. Finlande No. 23. (English summary.)

No locality was observed where the beds in which the ore occurs cut across neighboring beds, as might be expected in the case of intrusive sheets, nor were beds observed where great unexplained irregularities of iron content were present; a lean bed following along the strike did not essentially change its character, at least not more rapidly than would be found in a sedimentary ore. There are, interbedded with the iron ores, barren or lean layers composed of the same minerals as the ore gangue.

CHARACTERISTICS OF THE ORES.

The ore-bearing rocks are crystallized granular schists or gneisses which, so far as observed, have undergone the same degree of metamorphism as the remaining beds of the series. The ore occurs as more or less concentrated grains of magnetite (or hematite, in part), with quartz and feldspar and a little biotite. (See Pl. IV, *B*, p. 10.) The magnetite seems to have crystallized either just before or simultaneously with the feldspar and the quartz. A microscopic examination of a specimen of lean ore gave as its result plagioclase feldspar, largely albite, magnetite, and quartz, in the following proportions: Quartz, 50 per cent; feldspar, 26 per cent; and magnetite, 22 per cent. This is roughly equivalent to the following composition:

Composition of lean iron ore, Llano County, Tex.

Silica	67
Alumina	5
Soda	3
Magnetite	22

The wall rock of the ore (which is but a lean portion of the ore) showed approximately the following composition by microscopic analysis:

Composition of wall rock of iron ore, Llano County, Tex.

SiO_2	71
Al_2O_3	12
Na_2O, K_2O, CaO (largely Na_2O)	7
Magnetite	5
Biotite	3

A partial chemical analysis of the gangue of the Bader ore gives the following result:

Analysis of lean iron ore from the Bader incline, Llano County, Tex.

[W. T. Schaller, analyst, U. S. Geol. Survey.]

Silica (SiO_2)	57.31
Alumina (Al_2O_3) [a]	10.15
Ferric oxide (Fe_2O_3) [b]	26.66
Lime (CaO)	1.20
Potassa (K_2O)	.16
Soda (Na_2O)	5.93
	[c] 101.41

The same analysis, recalculated to 100 without iron to show composition of the remaining material, is as follows:

Analysis of lean iron ore from Bader incline recalculated without iron.

[W. T. Schaller, analyst.]

SiO_2	76.66
Al_2O_3	13.57
CaO	1.60
K_2O	.21
Na_2O	7.93
	99.97

The most interesting point in this analysis is the presence of sodium in excess of potassium, for the sediments of the region as a whole, including some of the iron ores, showed the latter in much greater abundance. This point will be discussed later.

The relations thus far pointed out indicate more or less strongly that the iron was present in the rock before metamorphism, for it follows the convolutions of the schists, may be traced long distances, was apparently crystallized before or at the same time as the accompanying minerals, and occurs in much the same relation as does graphite, a mineral without much doubt developed in this field in sedimentary material. Light is also thrown on the presence of iron in the rock before metamorphism by an occurrence of lean ores northwest of Bodie Peak, where the banded material carrying the magnetite has suffered brecciation by intrusion of granite. A thorough intermixing of the brecciated fragments and the intruding rocks has taken place. Locally the angular outlines of the broken fragments are very evident, but passing northward the fragments appear stretched and lentil shaped, and if the angular material had not been observed one might be at a loss to account for the lentil-like streaks. A microscopic examination showed an interesting distribution of the magnetite. It occurs both in the brecciated fragments and also between them, whereas the concentration was much less between the fragments than in them. This feature may indicate a more or less mobile state of the iron, due to the injection of granitic material. The microscope showed a granular mass of quartz and microcline feldspar (the latter dominant) and magnetite, with certain lens-shaped areas where the magnetite was heavily concentrated (the mashed fragments). In these areas quartz was almost wholly lacking, magnetite and feldspar being the minerals present. The writer believes that the magnetite found between the fragments was derived from the fragments of the intruded sediments and not from the intruding magma.

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[a] Including TiO_2 and P_2O_5, etc. The TiO_2 is present in small quantity, probably less than 0.5 per cent.

[b] Total iron, that is, $FeO + Fe_2O_3$.

[c] Summation high on account of reckoning FeO as Fe_2O_3. The correction to be deducted from the total is about 0.83 per cent.

BEARING OF IGNEOUS ROCKS OF THE REGION ON ORIGIN OF IRON ORE.

The basic intrusive rocks described above have no genetic relation, so far as observed, to the iron ore and they will not be discussed in that connection. That they may have been important, however, in effecting chemical changes in the sediments at the time of their intrusion will be pointed out later. The granitic rocks of the region, on the other hand, are intimately associated with the ores, and the hypothesis of a genetic connection with them may not be so readily dismissed.

As has been indicated, the iron ores are found in rocks believed to represent a sedimentary base and owe their origin either to replacement of metamorphosed beds, or to original deposition with or secondary introduction into unmetamorphosed strata. The granite, wherever found in association with iron ores, is intrusive into them, cuts across the bedding, or is interleaved with the ore beds. In fact, it presents exactly the same relations to the iron ore that it presents in numerous places to the mica, the graphite, or the hornblende schist series, into which group of rocks it can hardly be argued that the mica, the graphite, and the hornblende were introduced by the granite. In the case of the ore-bearing rocks, however, and also in the case of certain feldspathic schists, the mineral composition of the invading and the invaded rock is strikingly similar. The writer believes this to be a fortuitous condition, for, as is well known, certain metamorphosed sediments have a composition very similar to that of granite.

A very small percentage of magnetite, not more than ordinary, occurs in the granites of the region. In the pegmatites there are a few exceptions and in one instance a notable one. Near Gallihaw Crossing a pegmatite dike several feet thick was observed cutting across the schistosity of the mica schist series. It was composed of feldspar, magnetite, garnet, epidote, and limonite. The magnetite, which was abundant, occurred in irregularly shaped, often elongated masses throughout the dike and apparently crystallized simultaneously with the feldspar, though this is not certain. Bedded iron ores may exist not far distant from the locality, as small outcrops were seen. The dike apparently has had little contact effect on the schists which it cuts. It is suggested that it may have acquired its magnetite in passing through beds of iron ore. Where pegmatites occur in a region of abundant amphibole schist, hornblende was noted in the pegmatite, a fact certainly suggestive; and where pegmatite had cut limestone, scapolite was formed in the dike, clearly exhibiting the absorption of lime, though whether from the immediate vicinity or elsewhere is not certain.

In certain localities, where the effects of intrusion and impregnation have been most intense, abundant magnetite crystallized with feldspar has all the appearance of an original mineral in the granite magma; but never is the possibility absent that an iron-bearing sedimentary base has been absorbed by the intruding mass.

It is evident from what has just been said respecting the geologic relations of the granite to the schists that if the iron is a result of replacement, by means of magmatic emanations, some granite, other than the one now observed, was involved in the process.

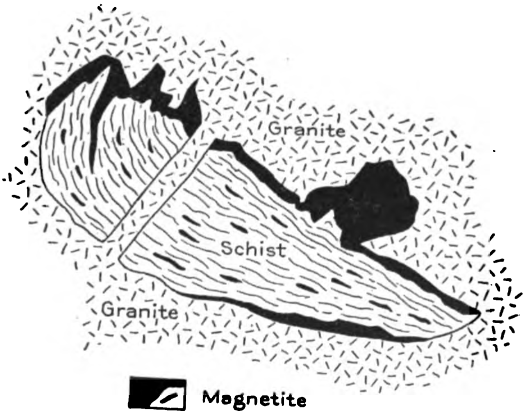

FIGURE 17.—Concentration of magnetite along edges of schist fragment at granite contact.

It is hardly conceivable that a granite presenting such indubitable evidences of its intrusive nature could have been the principal factor in the intense metamorphism observed, which is believed to be largely the effect of dynamic forces other than intrusion. The metamorphism was complete, or at least well under way, before the injection of the granite took place.

Though this statement seems to the writer a reasonably safe conclusion, it should be said that phenomena are observed locally which might be used as an argument for igneous introduction of the magnetite; such, for example, as the locality shown in the accompanying sketch (fig. 17). The clear evidence of crosscutting should here be noted, however, and the possibility of original iron in the schist kept in mind. On the north side of Llano River a short distance west of Hickory Creek the granites show almost completely absorbed schist fragments, in which but the faintest outline of the original fragment remains, indicated by broadly spaced lines of magnetite. (See fig. 18.)

It seems more probable that the granite, acting on an iron-bearing base, had by assimilation rearranged the quartz and feldspar, the iron remaining approximately in its original position, than that the granite had introduced this iron and then absorbed the schist.

CHEMICAL RELATIONS.

With the schist-gneiss group considered as a metamorphosed sedimentary series and the intrusive nature of the granite borne in mind, certain facts of general geologic application may have weight in arriving at a conclusion regarding the nature of the iron. It is a recognized fact in geologic science that the important result of regional metamorphism, in general, is a change of form rather than a chemical addition or subtraction. The schists of Llano County might well be the result of such metamorphism without any considerable additions. They are generally high in potassa and silica, two elements which Bastin[a] and others have shown are likely to be dominant in metamorphic sediments. Van Hise[b] points out that "quartz and acid feldspars have very nearly the same specific gravity, and unless such material be gradually contributed to the water so that it can be handled by strong waves and currents for a long time before final deposition quartz and acid feldspar will not be separated" and as the mica is carried away, "consequently in the comparatively shallow water along the shore, many nearly pure quartz-feldspar sands may be built up." Glauconite also is a deposit restricted largely to the borders of the continental shelf. He also says:[c] "From * * * muds carbonates are mainly removed in solution, the hydroxides are removed to some extent, and the highly oxidized iron largely remains." In regard to the pelite gneisses he says in part:[d] "While the greater part of the potassium probably passes into muscovite, where the potassa is abundant, a portion of it passes into feldspar, producing orthoclase and microcline, since these minerals are rather abundant in many of the schist pelites and gneiss pelites."

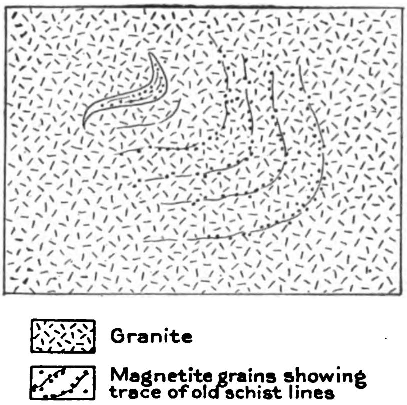

FIGURE 18.—Remnant of schist fragment in granite mass. Note lines of magnetite.

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[a] Bastin, E. S., Chemical composition as a criterion in identifying metamorphosed sediments: Jour. Geology, vol. 17, No. 5, 1909.

[b] Van Hise, C. R., A treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, 1904, p. 873.

[c] Idem. p. 889.

[d] Idem p. 900.

Grubenmann[a] also points out that "there occur marly sandstone or argillaceous marls, whose chemical composition approaches so nearly that of igneous rocks that confusion may arise in their discrimination."

The analysis of the wall rock at the Bader incline shows soda as dominant over potash. This relation was also observed at the Iron Mountain ore body. Iron ores in the western part of the quadrangle, however, are associated with a decidedly potassic gangue, as indicated by the prevalence of microcline feldspar. As normal sediments are in great part or entirely of the potash type, an explanation should be offered for the high soda content of this particular sediment.

As described earlier in this report, amphibolite and mica schists form a fairly definite unit in the schist series; it was also noted that amphibolites are occasionally found within the lighter schist series, and it was suggested that in many places they might be derived from basic sills intrusive into the sedimentary series prior to its deep burial and foliation. The contact metamorphism produced by such intrusion into clay shales has been studied in various localities throughout the world and in several places, at least, with the very definite and similar result of finding that soda and silica have been added and potash removed, but in the cases to be cited, without the addition of iron.

Though it can not be proved that the relations about to be presented existed in Llano County, they are given as a possible if not a probable explanation of present conditions; at the same time it is assumed that the introduction of soda took place prior to the deep burial of the rocks, with the result that under conditions of intense regional metamorphism and accompanied by complete recrystallization of the rocks albite was formed in place of microcline or orthoclase.

Teall, in British Petrography,[b] says:

> A striking feature [speaking of adinole, a rock produced by contact metamorphism of clay shale by diabase intrusion] is the large percentage of soda which the rocks contain. This has been proved by Schenck[c] to be due to an actual impregnation of the sediment with alkali derived from the eruptive rock. Thus at Bochtenbeck, by Niedersfeld, the unaltered rock contains 1.16 per cent of soda, the altered rock 4.94, 4.56, and 3.59 per cent; at Kuhlenberg, by Silbach, the unaltered rock contains 1.15, the altered rock 7.14 per cent; at Silberberg, the unaltered rock contains 0.50, the altered rock 6.03 per cent. We are thus led to the important conclusion that *the albite of the rocks altered by diabase is largely if not wholly a secondary product, due to the actual impregnation of the surrounding sediment by material derived from the eruptive rock.*

Rosenbusch,[d] in describing the contact effect of diabase sills on clay shale, says:

> These products of the innermost parts of the diabase contact areas are called adinole and are composed of an extremely fine-grained mixture of allotriomorphic albite and quartz, with which are very sparingly associated actinolite, epidote, rutile or anatase or even titanite.
>
> The chief difference between this and the deep-seated contact zone lies in the complete chemical changes of the schists.

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[a] Grubenmann, U., Die Kristallinen Schiefer, 1904, p. 12.

[b] Teall, J. J. H., British petrography, 1888, p. 220.

[c] Die Diabase des oberen Ruhrthals: Inaug. Diss. Bonn, 1884.

[d] Rosenbusch, H., Elemente der Gesteinslehre, 2d ed., 1901, pp. 346–347.

Analyses 1a–1c and 2a–2c and 4a–4c show different stages of change with increasing distance from the diabase.

One sees that the oxides RO and K_2O strongly decrease, while, on the other hand, SiO_2 and Na_2O considerably increase—that is to say, silica and soda are added in appreciable amounts to the schist substance.

	1a.	1b.	1c.	2a.	2b.	2c.	4a.	4b.	4c.
SiO_2	69.27	73.74	75.25	54.02	55.06	72.63	60.28	57.77	74.16
TiO_2							.69	.92	.37
Al_2O_3	13.12	14.81	11.80	21.22	19.75	15.81	22.61	19.35	11.85
Fe_2O_3	.62	.02	Trace.	2.51	1.83		2.53	1.29	.82
FeO	5.24	1.31	1.76	6.48	7.55	.74	.45	3.37	1.66
MnO	.09	.11		1.74			Trace.	Trace.	.06
MgO	1.36	1.29	1.57	3.01	2.21	1.21	1.35	4.35	2.10
CaO	.12	.61	.32	1.64	3.59	1.02	.13	1.71	2.10
Na_2O	2.25	5.47	7.54	3.36	7.51	8.33	.54	8.22	6.57
K_2O	4.31	1.51	.61	3.71	.84	.75	5.73	.22	.15
H_2O	3.36	.70	.81	1.97	1.83	.61	3.62	2.34	.52
CO_2	.04								.09
FeS_2	.62	.84	.49				.03	.04	.08
Organic substance	Trace.	Trace.		Trace.	Trace.		.97		.18
	100.40	100.41	100.15	99.66	100.17	101.10	99.57	99.76	100.76
Specific gravity	2.653	2.658	2.653	2.678	2.813	2.778			

J. Morgan Clements[a] has well shown the metamorphism produced in sediments by the intrusion of diabase dikes and sills. The changes resulting in a clay slate due to this influence are indicated in the following analyses. Clements was not able, because of poor exposures, to select his specimens with absolute certainty as to their exact distance from the diabase. He says:

> From previous determinations in other regions it is well known that the adinoles are next to the contact, while the spilosites (and desmosites) are intermediate between them and the clay slates. The following series of analyses are arranged in the order of approach to the dolerite, as determined by the character of the rocks:

Analyses of rocks from Lake Superior iron region.

	1.	2.	3.	4.
SiO_2	60.28	52.51	57.77	74.16
TiO_2	.69	1.70	.92	.37
Al_2O_3	22.61	19.00	19.35	11.85
Cr_2O_3		None.	None.	
Fe_2O_3	2.53	3.31	1.29	.82
FeO	.45	7.19	3.37	1.66
MnO	Trace.	Trace.	Trace.	.06
CaO	.13	1.55	1.71	2.10
BaO	.04	Trace.	None.	None.
SrO		Trace.	Trace.	
MgO	1.35	3.29	4.35	2.10
K_2O	5.73	.70	.22	.15
Na_2O	.54	6.72	8.22	6.57
Li_2O		Trace.	None.	
H_2O at 100°−	.60	[b] .34	[b] .18	.05
H_2O at 100°+	3.62	[c] 3.26	[c] 2.34	.52
P_2O_5	.03	.15	.04	.08
CO_2	None.	None.	None.	.09
S and SO_3		None.	None.	
C	.97			.18
Cl		None.	None.	
F		Trace.	None.	
	99.57	99.72	99.76	100.76

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[a] A contribution to the study of contact metamorphism: Am. Jour. Sci., 4th ser., vol. 7, pp. 81–91.

[b] H_2O at 110°.

[c] H_2O above 110°.

1. Clay slate, specimen No. 32497, U. S. Geol. Survey. Analyst, George Steiger.
2. Spilosite, specimen No. 32861, U. S. Geol. Survey. Analyst, H. N. Stokes.
3. Spilosite, specimen No. 32827, U. S. Geol. Survey. Analyst, H. N. Stokes.
4. Adinole, specimen No. 32465, U. S. Geol. Survey. Analyst, George Steiger.

In these analyses the usual increase of silica as the dolerite is approached is at once noticeable, and hand in hand with it goes the diminution in percentage of alumina and iron oxides. The content of water and carbonaceous[a] matter also suffers diminution, as was to be expected.

The most noteworthy difference between the clay slate and the contact rocks is shown in the relations of potash and soda. This is well brought out in an examination of analyses Nos. 1 and 2. It will be seen that there is only about one-eighth as much potash in the contact rocks as in the normal clay slate; while, on the contrary, about 12 times as much soda as there was in the slate has been added to the contact rock. This causes a reversal of the relations of the soda and potash, so that, whereas in the clay slate there is present 10 times as much potash as soda, we find in the contact rock taken as an example very nearly 10 times as much soda as potash. * * *

The very considerable changes which are shown by the above analyses to have taken place in the metamorphism of the slates, especially the changes in the amount of silica and soda resulting in the production of albite in large quantity, seem to add weight to the supposition that in such contacts an actual transfer of material, possibly in the form, as has been suggested by others, of the soda-silicate, does take place from the basic igneous rock to the intruded slate.

In summing up, then, it may be said that the light-colored schist series as a whole are eminently quartzose potassic rocks; that it is important to recognize the fact that introduction of material in the deep-seated zone, except on a very minor scale, is not necessary to account for their chemical composition; and that the introduction of soda may have taken place at the intrusion of the diabase-like rocks prior to deep-seated conditions.

Attention should here be called to the potassic composition of the lean ores in the extreme western part of the area and to the possibility of their derivation from glauconitic sediments. That glauconite is capable of altering to magnetite can not be questioned. J. K. Prother[b] says, in describing the glauconite from the greensands of New Jersey: "In some glauconite grains are rows of small grains of magnetite. All gradations are noted from unaltered glauconite to glauconite changed to a network of magnetite—magnetite is seen filling the cracks of glauconite."

It is reasonable to suppose that such a process may have operated in the case of the ores under discussion.

It would seem extremely probable that if the siliceous glauconite beds of the Cap Mountain formation, for example, were subjected to metamorphic conditions, potassic feldspars, quartz, and magnetite would result.

PROBABLE CONDITIONS AT TIME OF INTRUSION.

In attempting to state the reactions taking place at contacts of igneous masses with sedimentary rocks at great depths, one is forced to base conclusions on phenomena only imperfectly understood. It is all the more important, then, to refrain from speculation and to confine oneself to reasonable analogies.

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[a] The carbon in Nos. 2 and 3 was not determined.

[b] Jour. Geology, vol. 13, p. 511.

If we make the assumption for a moment that gaseous solutions capable of carrying iron into the schists were present at the time of intrusion, an examination of the conditions probably obtaining in the wall rock at that time do not give much if any support to the idea that such replacement would have taken place.

Field evidence shows that the schists were in large part in the zone of flowage, where openings in the rocks, if existing at all, were subcapillary, producing practically impervious strata. The crystalline interlocking of the iron with its accompanying minerals indicates that the iron was present at the time of crystallization, which preceded the intrusion of the granite. Many crystalline limestones were observed which showed no evidence of replacement, and where limestone has been converted into wollastonite, as is the case in the lower (lighter) schist series (Valley Spring gneiss), it is not certain that the effect was not due to thermal metamorphism of impure limestone. In this case CO_2 was expelled. Barrell [a] holds that—

> Carbonic acid is only expelled when the siliceous impurities of the limestone are sufficient to combine with the lime set free, forming lime silicates. This ability of *deeply buried* [b] limestones to retain their carbonic acid when intensely heated, if free from other impurities, has been noted by a number of observers.

A consideration of the chemical nature of the remaining beds other than limestone places them in a class even more chemically inactive than the limestone, so far as replacement is concerned; for they are siliceous rocks, and as such notably inactive except where pore space (including fractures) exists.

The study of rock magmas has shown the probability that when molten they exist as silicate solutions (various silicates in mutual solution); further, that as crystallization ensues, the remaining magma becomes progressively more siliceous. In such a system pegmatites become end products of crystallization. Harker[c] regards a rock magma as—

> A definite mixture of silicate compounds, the only free oxides present, at least in a magma approaching the point of crystallization, being those parts, if any, of the silica, alumina, ferric oxide, and water, which after crystallization appear as quartz, corundum, hematite, and free water.

Moreover,[d] he regards mineralizing substances such as water, chloride, fluoride, etc., as "an integral part of the rock magma itself," and considers them "operative throughout the whole progress of consolidation of the magma. * * * The pegmatites [e] themselves represent the watery residual magma, except that the greater part of the water and other volatile substances was expelled in the final crystallization."

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[a] Barrell, Joseph: Am. Jour. Sci., 4th ser., vol. 13 p. 279.

[b] Italics by present writer.

[c] Harker, A. H., The natural history of rocks, p. 166.

[d] Idem, p. 288.

[e] Idem, p. 295.

At this stage of consolidation should exist the most perfect opportunity for a liquid substance to permeate the rocks; but this has not taken place except in a mechanical way by interleaving or crosscutting, though these processes have locally proceeded in a most intricate manner. It is probable that the water and the silica of the final product are represented in the quartz veins, which are very numerous in this region; but this mode of entrance into the schist shows clearly that the easiest avenues were chosen, namely, fractures and cleavage planes.

> With the completion of crystallization in a rock magma[a] the contained water and other volatile substances * * * must be disengaged. We must suppose a certain leakage by diffusion into and through the contiguous country rocks; but it is probable that this escape is not important until the temperature has fallen considerably.
>
> High temperature,[b] which in liquids diminishes viscosity and so promotes diffusion, has the opposite effect in gases; and in view of all the conditions it is likely that a large part of the volatile constituents is in general retained down to a late stage. Nevertheless, more or less of the water and other gases must pass into the neighboring rocks while these are still heated by the intrusion.

Such transition, it is believed, can occur only where pores or fractures exist, or where pressure is so slight as to permit the ready expulsion of CO_2 (in the case of limestones) to admit the entrance of solutions, or where chemical interchange is possible. It is extremely doubtful if solutions capable of producing magnetite, quartz, and albite can permeate a nearly impervious siliceous formation for any great distance. Assuming that they have done so in this region, they could not do more than progressively fill the minute cavities found; for it is known that silicate rocks are those which offer the greatest resistance to attack, and the relation of the iron minerals in the schists is of the same nature as that of the albite and the quartz which accompany it.

The local abundance of magnetite in the pegmatite might be advanced as an argument for the igneous introduction of the iron into the schists; if, however, a quantitative analysis were possible over a broad area the writer believes it probable that the iron ratio to pegmatite would be shown to be much the same as is the iron ratio in the granites to the parent magma. The extreme fluidity of the pegmatite material should offer favorable opportunities for such segregations of iron minerals as are found, without postulating any great quantity of iron when compared with that found in the body of the schists.

The ratio of phosphorus to iron in the Llano ores is interesting. Practically all the analyses at hand show a very low content of phosphorus; that is, Bessemer grade. An examination of sedimentary ores the world over shows, for the most part, phosphorus in greater quantities than Bessemer practice permits. It would seem necessary, therefore, if these ores are to be assigned to a sedimentary origin, to offer some explanation of this divergence. It should be pointed out that the Bessemer limit, as a point on a scale of phosphorus content, is a low point, and that its delicacy being considered, this limit might easily have been disturbed by conditions not understood and now hidden by the metamorphism which has taken place.

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[a] Harker, A. H., op. cit., p. 299.

[b] Idem, p. 303.

Van Hise[a] gives as the result of an analysis of 78 shales an average content of 0.17 per cent phosphorus; of 624 sandstones, 0.07 per cent. The Llano ores may well have been deposited with arkosic sandstone. It must be admitted, however, that the presence of the iron in sedimentary deposits seems to involve the presence of phosphorus and that therefore this comparison loses some of its value.

It is credibly reported that certain stock piles in the Lake Superior region originally above Bessemer grade have by processes of weathering been leached of sufficient phosphorus to render them of Bessemer grade.

It is possible, then, that in the case of the Llano ores, first, that only a small percentage of phosphorus was deposited with the ore; or, second, that by some process of leaching phosphorus was removed; or, third, that unknown reactions due to metamorphism have served to remove or lower the phosphorus content.

It should be said also that those magnetite deposits of the Adirondacks to which an igneous origin has been ascribed by careful workers contain from 0.01 to 2 or 3 per cent of phosphorus; but this fact, though it could be legitimately used as an argument against igneous origin, does not alter any value the low content of phosphorus may have as an argument against sedimentary origin.

COMPARISON WITH OTHER REGIONS.

Beck,[b] in describing the iron ores of Krivoi-Rog, in southern Russia, says:

> These ore deposits,[c] ordinarily grouped as those of the Saxagan basin, lie on the Inguletz, a western tributary with north-south course entering into the Dnieper River above Cherson. They are of exceedingly great importance to Russia, because they lie close to the Donetz coal basin extending east of the Dnieper. The ores occur in a strongly folded crystalline schist striking north-south, whose geologic age is as yet uncertain. In its upper part this rock consists of carbonaceous slate with but

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[a] Van Hise, C. R., A treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, 1904, p. 975.

[b] Beck, R., The nature of ore deposits (tr. by W. H. Weed), p. 75.

[c] See reviews of the works of Kontkiewitsch, Platnitzky, Domherr, Monkowsky, Karpinsky, and others in Zeitschr. prakt. Geologie, 1896, p. 271; 1897, pp. 182, 186, 278, 374; 1898, p. 139 (Macco). See also Strippelmann, L., Süd-Russlands Magneteisenstein und Eisenglanzlagerstätten in den Gouvernements Jekaterinoslaw und Cherson, 1873; and Cordeweener, J., Géologie de Krivoï-Rog et de Kertsch, Paris 1902.

few layers of ore; next below come the ore-bearing quartzite schists, underlain by clay slate, actinolite schist, quartz chlorite schist, talc schists, arkose, and itacolumite, like mica schists, and finally by gneiss (probably dynamometamorphic granites) and true granites. The ore-bearing strata form a long-extended fold, and show a close minor plication by which quartzite beds have, according to Macco, changed into a succession of quartzite nodules, like conglomerate cobbles in a clay slate. In the double row of deposits extending parallel to the Saxagan River the two most important ore bodies are those near Krivoi-Rog; the lower one about 98 feet (30 meters) and the uppermost about 262 feet (80 meters) thick. The ores consist of magnetite, for the most part altered to red hematite, with 45 to 70 per cent of iron and 0.01 to 0.02 per cent P_2O_5. The very irregular ore masses lie in a finely banded yellowish white, red, or brown ferruginous quartz schist whose crystalline quartz grains inclose numerous magnetite particles.

Newland,[a] referring to nontitaniferous iron ores in the Grenville series of the Adirondacks, says:

> There can be no doubt that the form assumed by the ore bodies is conditioned by the structures of the inclosing rocks. * * * This feature is least apparent in the gneisses of the igneous series, and most evident in the banded gneisses and schists of the Grenville. The ores consequently must have been deposited before the great regional disturbances took place, or at least before the rocks received their present structural arrangement.

Though Newland found it difficult or impossible to determine the origin of some of the iron-ore deposits in the Adirondack region, he regarded the origin of others as quite obvious. For example, describing the deposits near Crown Point, on Lake Champlain,[b] he says:

> The magnetites * * * are associated with banded gneisses and schists that can be classed without reserve in the sedimentary or Grenville series. They have a simple tabular or lenticular form, swelling and narrowing to some extent along the strike and dip, but otherwise are little disturbed. * * * The Grenville rocks which occur near the ores are mostly hornblende and biotite quartzose gneisses with occasional intercalations of thin-bedded schists. They are conspicuously foliated and variable in their composition from layer to layer. * * * The Grenville has been broken up into patches and larger irregular areas by granite which has invaded the series from below. * * * The granite frequently cuts across the stratification of the sediments and sends off dikes and stringers which penetrate the latter in all directions.

Other instances might be cited where field relations point to the conclusion that metamorphosed sediments are the base of the iron-ore formation and that metamorphism has in all probability preceded granitic invasion, but the localities mentioned are sufficient for the purpose.

SUMMARY.

In conclusion it may be said, as Van Hise[c] has so well pointed out in referring to the distribution of the elements—

> that a general result of metamorphism and accompanying processes is that many of the secondary rocks are depleted in reference to each metal and that correlative with

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[a] Newland, D. H., Geology of the Adirondack magnetic iron ores: New York State Mus. Bull. 119, 1908, p. 27.

[b] Newland, D. H., op. cit., pp. 40-41.

[c] Van Hise, C. R., A treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, 1904, p. 1035.

such depletion other deposits are formed in which each metal is segregated. Since these processes result in deposits in which each of the common metals is segregated, why should we hold that the metal of a present deposit of gold or silver or copper [or iron][a] is derived solely from an immediately adjacent igneous rock unless evidence for this be conclusive. The natural view is that the metallic ore deposits of the world are broadly accumulated results of the processes of segregation carried on throughout geological time.

The geologic events probably involved in the formation of the Llano ores may be indicated as follows:

1. Deposition of iron as oxide, carbonate, etc.,[b] with the sediments, either in extended basins or along borders of the sea.
2. Burial and intrusion of dikes and sills of a diabasic type with possible local introduction of soda. Possibly granitic intrusions.
3. Deep burial with following folding and metamorphism, and second intrusion of basic types.
4. Intrusion by granite magma with great local disruption.
5. Elevation above sea, and exposure by erosion.

GOLD.

Small quantities of gold may be found at many localities throughout the pre-Cambrian area. It must be said, however, that in general the quantity is so small as to be valueless from the standpoint of a mining enterprise. Results of many assays made of specimens said to contain gold were decidedly discouraging. The following table shows the results of a number of assays:

Results of assay for gold and silver, Llano County, Tex.[a]

	Gold, per ton.	Silver, ounce per ton.	Locality.
1	Trace.	Trace.	Sulphides from Mr. Sheeon's place, 4 miles south of Llano.
2	None.	None.	Graphitic schist 2½ miles southwest of Niggerhead Mountain, three-fourths of a mile east of the Colorado (flowing south) and a scant half mile north of the river (flowing east).
3	Trace.	.56	Thomas Prospect, Hooking Hollow.
4	None.	None.	Shaft near Gallihaw Crossing. Pegmatite dike.
5	None.	None.	2½ miles east by north from Granite Knob and one-fourth mile south of the east and west road, near edge of sheet. Gossan from vein.
6	Trace.	.38	4 miles west of Burnet and north of Spring Creek, Bailey Prospect.
7	$0.31	None.	Quartzite-like rock near Parkinson's quarries, 110 feet long, 30 feet wide.
8	.10	None.	Iron oxide 1¾ miles east-northeast of Field Creek village.
9	.10	None.	Edwards's pasture, near east boundary 2-foot vein, 240 feet long (by float). Prospect holes 5 miles east by south of Valley Springs.
10	None.	None.	Southeast of No. 9 and west of Pecan Creek, north of road to Edwards's ranch. Bedded layer in graphite schist.
11	.10	None.	Willow Creek above Burnet-Valley Springs road; outcrop about 2½ miles west of Valley Springs.
12	.10	None.	Heavy pyrite gossan in graphite schist on knoll 1½ miles west by south of Miller Mountain.

[a] Assays 1-6 by E. E. Burlingame Denver, Colo. Assays 7-12 by Ledoux & Co. New York City.

On Henry H. Sheeon's place, about 4 miles south of Llano, a shaft has been sunk to prospect pyrite veins in the quartzite schist. The pyrite nearly or quite accords with the bedding of the schists which at this point dip steeply to the southeast. The iron mineral is accompanied by much quartz in narrow veins swelling and pinching in the layers of the schist. Apparently the two were introduced together. An assay of this pyrite, which is very abundant, judging from the dump (the shaft, unfortunately, was not open at the time of the visit), shows no gold.[a]

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[a] Inserted by present writer.

[b] The chemistry of the possible manner of original deposition need not be discussed here, as little or no evidence is at hand for discrimination.

The only prospect visited where gold was present in sufficient quantity to warrant further prospecting is called the Heath mine. This prospect is located 5 miles northeast of Llano, just north of the Llano-Lone Grove road. At the present time the property is controlled by Mr. McCarty Moore, of Dallas, Tex., though during the past 25 years a number of persons have been interested in the prospect.

The rocks in this vicinity are a part of the dark (Packsaddle) schist series. Graphite and mica schist and limestone are present. At the prospect, intrusive granite, which to the south and east occurs in large masses, has broken the regularity of the beds, and strikes and dips with quite variable angles may be observed. Much quartz and pegmatite have interleaved and cut the schist beds, and pyrite is locally present. It is with the quartz stringers that the gold seems to be largely associated.

In the subsoil and in the partly decayed schists below, where exposed in crosscuts, a canary-yellow efflorescence or stain may be noted coating quartz stringers and distributed in spots through the decayed rock. This stain has been mistaken occasionally for an oxidation product of gold tellurides. An examination by W. T. Schaller of the United States Geological Survey proves the material to be a compound of bismuth and vanadium. The only known mineral compound of bismuth and vanadium is the mineral pucherite, which, however, is always found in crystal form. The yellow compound has been noted by Mr. Schaller in California where he collected sufficient material for an analysis, results of which will be published at a later date.

The prospect is located on a low spur rising to the north. A cover of residual red and brown soil effectually conceals the underlying decayed schists and granites. This residual soil carries gold, undoubtedly concentrated by the removal of soluble and easily transported constituents of the rock. Values are also reported in the underlying schists.

Figure 19 is a sketch map on which are shown the positions of some of the open cuts and shafts by which the property has been prospected. The map also shows the general northwest trend of the schists and the variable dips and strikes that may be observed.

In 1900–1901 a shaft 615 feet deep was sunk. Gold is reported from this shaft, but little definite information could be obtained as to its value or the depth at which it occurred. The writer was informed that an 8-foot band of black schist carried fair value in gold associated with molybdenite.

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[a] See table on page 70, assay 1.

The material on the dump shows that the lower portion of the shaft penetrated feldspar-mica schist and fine-grained pink intrusive granite.

At points 5 and 6 shown on the sketch map two 50-foot shafts have been sunk and connected by a drift. The results of any systematic sampling of these openings are not at hand. High values are not reported. At point 7 shown on the sketch map two shafts 45 feet deep are sunk in schist and intrusive granite. An open cut following a quartz vein is also located at this point. The presence of pyrite with the quartz and in the granite is noteworthy. Open cuts are located also, as indicated at 1, 2, 3, and 4, and a shaft is sunk as indicated at 11.

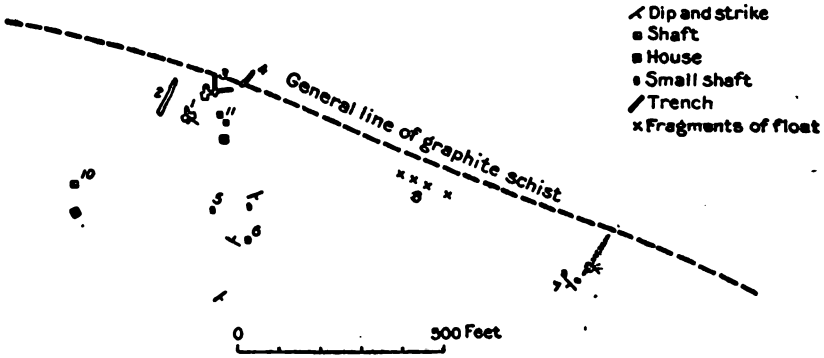

FIGURE 19.—Prospect pits and shafts at Heath gold prospect.

It has been pointed out that a foot or more of residual soil covers most of the bedrock in this vicinity. This soil has been sampled by 60 shallow pits in addition to the open cuts shown on the sketch map. A sample selected with great care by the writer from one of these pits gave an assay of 20 cents in gold.

An incline has been run from the surface crosscut shown at 1 on the sketch map (fig. 19) southward down the dip of the schists for about 90 feet. A sample from the west wall of this incline, about 30 feet from its upper end, was cut from the grass roots down to the bottom of the cut, a distance of 9 feet. The sample was crushed on a canvas sheet, mixed and quartered twice, and assayed for gold and silver, and $1.60 in gold was reported by the assayer.[a] A second sample from the east wall and 12 feet farther down the incline was cut from 6½ feet of material. The top of this cut was 7 feet below the grass roots. The sample was quartered once and assayed for gold and silver, and 20 cents in gold was reported. A third sample was taken from the west wall 42 feet down the incline from second sample. This sample covered 4½ feet of material and was 5 feet from the face of the incline. It was quartered once and assayed. No values were reported.

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[a] Assays made for the U. S. Geol. Survey by E. E. Burlingame, of Denver, Colo.

A sample was taken from crosscut 3 (see sketch map) on its south side. It included 6 feet of schist and a little granite. It was quartered once and assayed. No values were reported.

Crosscut 2 (see sketch map) was sampled at three points about 75 feet apart, two on its northwest side and one on its southeast side near the northeast end. The three samples, covering in all about 10 feet of vertical material, weathered schist and soil, were mixed together and quartered once and assayed. No values were reported.

A sample was taken from the top of 26 ore sacks and from an ore pile representing picked ore selected by panning tests. This sample assayed $20.59 a ton in gold and silver, of which 19 cents was silver.

The company has had many assays made of material from the surface and from the cuts and the incline. Separate assays of quartz from veins have also been made. In all these instances, values higher than those found by the writer are reported. In some instances single stringers of quartz are reported to carry exceptionally high values. The sample from the ore sacks, noted above, was of very quartzose material.

It seems very probable that in large measure the values are confined to the quartz veins; these are abundant locally, but are not persistent and are not of such size that they could be worked individually.

Except in the residual material, in which there has been opportunity for enrichment by the removal of soluble constituents of the rock during its decay, it is doubtful if sufficiently high values in gold could be relied on to insure profitable mining. This point, however, can be determined only by assaying many carefully taken average samples.

COPPER.

No encouragement can be given that any copper prospect visited during the course of the investigation on which this report is based can ever be of commercial value.

About one-half mile northwest of Wilberns Glen on both sides of the road some crosscuts and a shaft about 35 feet deep have been opened. Films of malachite were noted associated with epidotized and garnetized schist.

About three-fourths of a mile beyond the western edge of the Llano quadrangle and about 400 feet south of the Mason road prospecting has been done on what is known as the Bauer prospect. At this point schists striking east and west are near the edge of a large mass of fine-grained granite. A shaft (slope) of unknown depth dips 50° S. Carbonates are noted over about 150 feet of prospected ground. No sulphides were seen on the dump. A little garnet was noted. Two carloads of ore are reported to have been shipped.

In May's pasture, 2 miles south of Babyhead and a short distance east of the Llano-Babyhead road, a fine-grained pink granite is seen carrying malachite and some azurite. About two tons of 3 per cent rock is at the surface. A small trench has been made.

There has been prospecting for copper on Adolf Schneider's place, 1½ miles north of Llano River, and 5 miles east of the Mason County line, on a stream joining the Llano above Bauer's ford. Three holes from 15 to 30 feet deep have been sunk in schists which strike north and dip about 35° E. A little chalcopyrite associated with black garnet, epidote, quartz, and a little calcite may be seen in a layer of schist. Carbonates extend down only a few feet, and but little gossan is seen. The occurrence is on the west side of a tongue of fine-grained red granite which crops about 30 feet down the dip to the east.

Chalcopyrite and a little chalcocite were seen in the intrusive granite as well as in the schists, and a microscopic examination showed clearly its secondary nature—that is, it in part fills the cracks in feldspars. The solutions therefore which brought in the copper penetrated the rocks later than the intrusion of the granite and took advantage of existing fractures.

An assay of a sample representing about 200 pounds of ore selected by Mr. Schneider gave the following result: Gold, $0.41 per ton; silver, trace; copper, 0.94 per cent.

About 2 miles east of Magill Mountain and a short distance east of Pecan Creek, prospecting for copper has been carried on. Several shafts and crosscuts have been opened. At this point the pre-Cambrian schist series is cut by a network of pegmatite and quartz veins, the latter often paralleling the lamination of the flat-lying schist. The schist and the pegmatite also contain disseminated pyrite, chalcopyrite and bornite, with malachite and azurite. The prospects do not indicate a deposit of value.

In the town of Llano and in the near vicinity several pits have been sunk in the hope of developing a copper property, but nothing was seen which would invite further work.

Other prospect pits were seen at various localities, but in no instance were any of the showings of such a nature as to warrant further prospecting.

LEAD.

About 3½ miles north of Bluffton, Burnet County, on Silver Creek, a tributary of Beaver Creek, a small area of coarse pink granite protrudes beneath the Cambrian strata, and around the edges of this outcrop galena may be observed in the limy glauconitic quartz sandstone, which here rests by overlap on the granite. About 1½ miles north by west of this locality a similar occurrence is found on Beaver Creek, where again galena occurs in glauconitic sandstone near the base of the sandstone series and just below an outcrop of pre-Cambrian granite (on the creek). The locations of Beaver and Silver Creeks are shown on the map (fig. 20), and the geologic relations at the Silver Creek locality are shown in figure 21. It may be seen from these figures that at this point overlap occurs, because of the unevenness of the pre-Cambrian floor on which the sediments were deposited. It will be noted also that quaquaversal dips occur along the borders of the granite mass. In the field small faults accompanied by zones of slipping and brecciation were developed along this unconformity. These, with the steep dips (confined entirely to the contact), plainly indicate an upward movement of this granite mass, a movement of sufficient magnitude to flex the beds sharply, but not sufficient to do more than break them slightly. The structure at the locality on Beaver Creek is of the same type, though in that locality the folding of the beds due to a sharp uplift is even more beautifully shown (Pl. V, *A*).

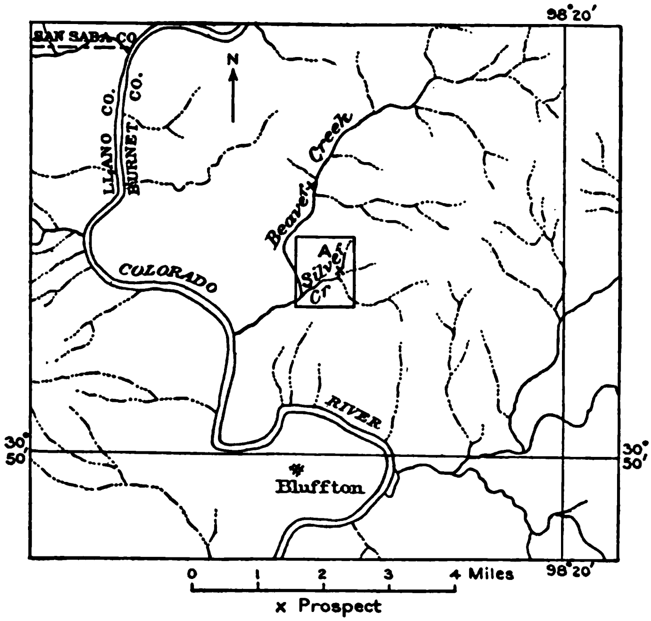

FIGURE 20.—Map showing location of lead prospects north of Bluffton and area (A) covered by figure 21.

The lead occurs apparently as a replacement of the limy sandstone, though it is not confined to that member, being found also locally in the limestone. It can not be said to follow the bedding consistently, though locally it may do so. It is found both near the granite floor and also a considerable distance, 40 feet or more, above it. A microscopic examination shows that the galena is most likely a replacement of the calcite which binds together the quartz and glauconite grains making up the sandstone.

Two shafts and a tunnel have been opened on the property. Only the tunnel was in condition to be examined. From the 65-foot shaft two or three veins of lead are reported by Dr. Osborne, who owns the property. Sixteen feet from the top of this shaft a vein reported 3½ feet thick is said to run 75 ounces in silver and 20 per cent lead.

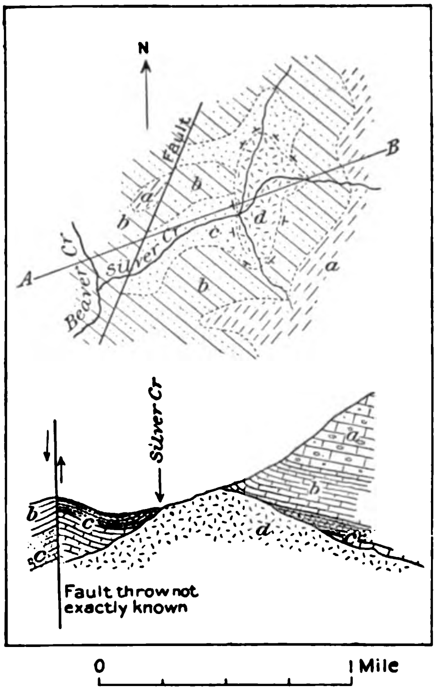

FIGURE 21.—Plan and ideal section showing relations of Upper Cambrian to underlying pre-Cambrian granite at lead prospects north of Bluffton. *a*, Ellenburger limestone; *b*, Wilberns formation; *c*, Cap Mountain formation; *d*, pre-Cambrian granite.

Some of the galena from this locality was examined for its silver content.[a] The method used, with the quantity of sample submitted, would not detect less than 8 ounces of silver per ton. No silver was detected.[b]

The tunnel is located a short distance south of Silver Creek on the western contact. It is run S. 68° W. in glauconitic sandstone. Thirty feet in, a crosscut is driven 7 feet northwest and 18 feet southeast. A bed of sandstone about 18 inches thick is here seen dipping 23° SW., and shows a little disseminated galena. At the end of the crosscuts and also at a point near the tunnel the drift has been widened, evidently for the purpose of following a body of ore which gave out. The tunnel was continued beyond the drift, but is reported to have struck no lead.

The origin of an ore deposit generally has an important bearing on a decision regarding the probabilities of developing a commercial deposit. The following suggestions are offered as an explanation of the occurrence described, but the writer does not thereby wish to

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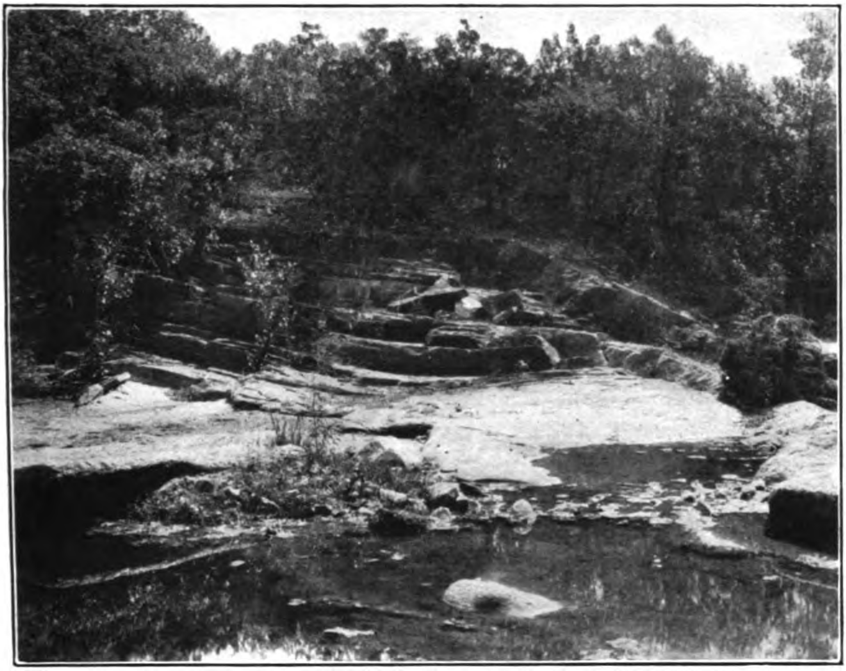
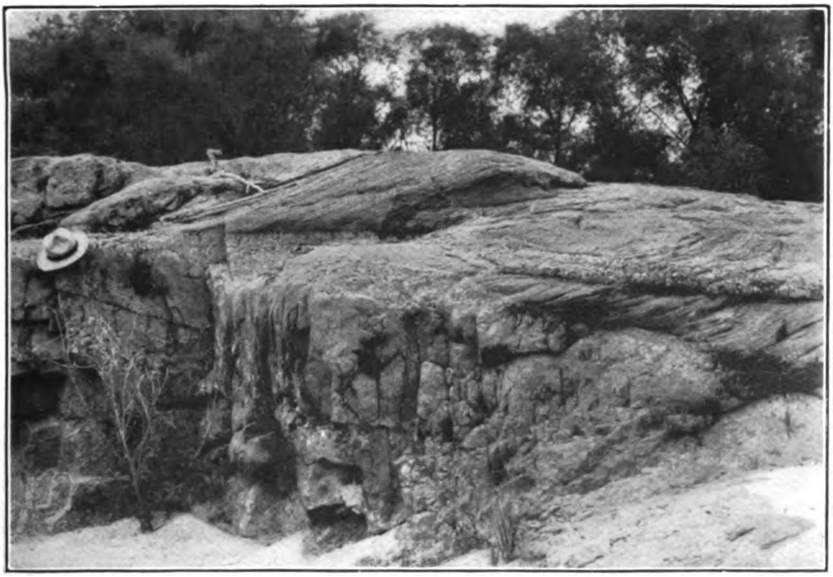
[a] W. B. Phillips (Eng. and Min. Jour., vol. 77, 1904, p. 364) reports the lead-bearing strata on Silver Creek to be 6 to 12 feet thick. Assays show between 10 and 20 per cent lead with no silver or gold.

[b] Munroe, Hall & Hopkins, chemists, assayers, engineers, Washington, D. C.



A. FOLDING OF UPPER CAMBRIAN SANDSTONE ON BEAVER CREEK, NEAR LEAD PROSPECT.

See page 75.



B. PEGMATITE AND GRANITE INTRUDING SCHIST.

See page 10.

create an optimistic sentiment regarding these ores; it can not be said that the prospects which were available for study would warrant such a view.

It is significant that in both the localities described the lead is concentrated in an area of local disturbance, where a dome-like uplift has to some extent brecciated the rocks and caused small faults to appear. It is noteworthy also that the pre-Cambrian basement at this point is about 100 to 150 feet higher than the pre-Cambrian floor to the west. Seventy to 90 feet above the glauconite horizon occurs a shale member of sufficient thickness to act as a fairly impervious cover. Waters carrying lead in solution circulating under artesian conditions might flow upward along the unconformity, reach this locality of relatively open space, and deposit lead sulphide. The chemical reaction which caused this precipitation must remain conjectural. If the deposition be due to any inherent quality of the inclosing rock, one would suspect that the presence of glauconite might have played a part.

It is interesting to note that this galena occurs in a series which is lithologically very similar to the Lamotte sandstone and the dolomitic Bonneterre limestone of southwestern Missouri, where workable ore bodies are found both in that sandstone and in the limestone above. If these Texas occurrences are of a similar type to those of southwestern Missouri, much irregularity may be expected in their distribution. Though many faults occur in the Texas region, some of considerable throw, they have no apparent connection with the galena other than the local effect due to the formation of open space by the brecciation described above. Considering their proximity to the basal unconformity and the presence of the shales above, it is suggested that the deposits owe their origin to lead-bearing solutions more or less controlled by the relatively impervious pre-Cambrian floor below and the relatively impervious shale above, moving laterally in past time under artesian conditions, the lead in solution having been derived by leaching from many feet of higher strata perhaps many miles distant from the present deposit.

GRAPHITE.

As the series of pre-Cambrian rocks described above were in part originally shales, sandstones, and limestones, they are now represented by schists of varying composition. Moreover, certain constituents have become, through metamorphism, of possible economic importance. Such an instance is the change of carbonaceous matter originally in the shales to graphite.

Graphite-bearing schists are widely distributed throughout the pre-Cambrian rocks, though the content of graphite is variable. In most places the graphite schists are associated with limestone or marble, a natural occurrence, for carbonaceous shales are often associated with limestone strata. Many of these schists can be traced for long distances.

Graphite-bearing schists were noted at many localities, but since only one of these is as yet considered of importance, a description of the occurrence at this locality will serve as a measure of those left undescribed; for it may be said in general that it would not be advisable to spend money on prospecting or testing at other localities until the deposit in question is proved a commercial success. If any exception be made to this statement, it would be that perhaps certain beds carry sufficient graphite to be of value as a source of paint pigment, in the industrial manufacture of which a very impure graphite can be used, as not more than 35 or 40 per cent of graphite is required in the paint pigment, the remainder being generally siliceous, aluminous, or ferruginous material.[a]

The locality which has received and warranted the most attention is located 1⅞ miles due south of Lone Grove, is approximately 1,500 feet west of Little Llano River and 800 feet north of the Houston & Texas Central Railroad.

The graphite occurs in graphitic schists of the upper or black series which in this vicinity contains considerable limestone. (See map, Pl. III, in pocket.) Granite and pegmatite intrusion has locally disrupted the beds to a greater extent than can be expressed on a map of the scale here published.

The graphite-bearing schists can be traced with interruptions for one-half mile northwestward from a point a little west of the railroad bridge, through the present workings, to a point where the series disappears beneath overlying Cambrian sandstones. Graphite is also reported across the river in the same trend.

The deposit has been prospected by a shaft with underground workings and by a number of surface cuts, four or more in a distance of about 500 feet. Two to the southeast of the shaft (about 150 and 300 feet from it, respectively) only show granite débris. One to the north of it about 150 feet is badly filled. A 70-foot cut about 25 feet north of the shaft gives an excellent exposure.

At the west end of the cut, a mixture of schist and pegmatite with calcite veinlets is exposed for 22 feet. There is a little graphite in the schist. Limestone is exposed in the extreme west end. Next to this 22 feet of lean material, an irregular mass is exposed, about 3 feet across and extending from the bottom to the top of the cut. It contains considerable graphite, mixed with quartz, feldspar, and calcite and represents a rich graphite-bearing layer intruded and broken by pegmatite with subsequent filling of fractures by calcite.

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[a] Bastin, E. S., Graphite: Mineral Resources U. S. for 1908, pt. 2, U. S. Geol. Survey, 1909, p. 720.

At a first glance the impression might be formed that pegmatite had introduced the graphite. A careful examination of the graphite bunches in the pegmatite shows, however, that they represent broken fragments of schist. A specimen was polished and etched with hydrochloric acid, which by dissolving out the calcite contained between the laminæ of the schist fragments showed clearly the schistose nature of the graphite.

Following this mass is 6½ feet of fine-grained mica schist, carrying a small content of graphite, after which is exposed 6 feet of material similar to the 3-foot irregular mass described above. Seven feet of schist, practically barren of graphite, is followed by 25 feet of material similar to the irregular mass of graphite, feldspar, and quartz, but containing more of the latter material as the end of the cut is approached. Decayed granite appears in the east end of the cut.

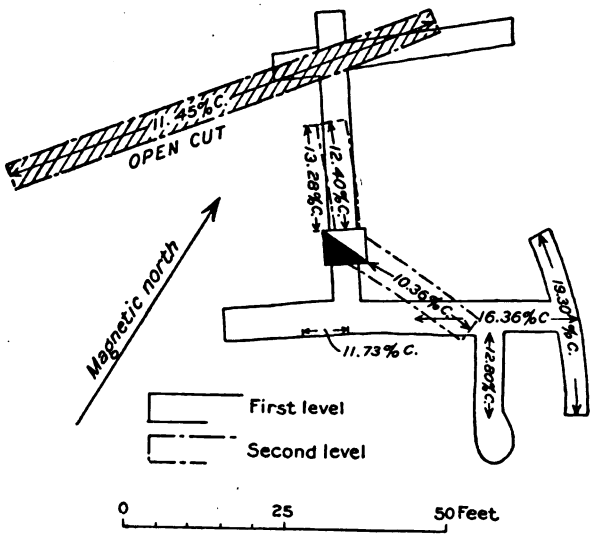

FIGURE 22.—Plan of workings at graphite property near Lone Grove.

The underground workings were not open at the time of the writer's visit.

An average sample taken over the length of the cut described above showed a carbon content of 11.45 per cent.

The locations of the shaft, cut, and underground workings are shown in figure 22. The first level is 55 feet below the collar of the shaft, the second 28 feet below the first. In addition to the workings shown in this figure is an exposure of some 5 feet of graphitic material in a small pit about 150 feet northwest of the shaft, and about 300 feet northwest of the shaft is a long crosscut 10 or 12 feet deep in greatly decomposed schist and gneiss, practically barren.

A private report made in 1902 by William Young Westervelt and furnished by the courtesy of Mr. R. H. Downman contains many interesting data on this property, and the following notes are abstracted from it:

> The only point at which sufficient development work has been done to actually place "ore in sight" is at the shaft and associated workings, represented by the accompanying plate.
>
> The shaft, for the first 5 feet, is built up through the dump, but with this exception is entirely in a mass of graphite ore from its collar to the first level. There being neither timbers nor ladderway in the shaft, except at the collar and levels, it was impracticable to take a sample of it. Careful samples of the levels and of the sump being secured, however, sampling of the shaft was not deemed necessary. On the first level, a drift runs northwest on a seam of graphitic shale about 5 feet wide, which is proved to exist for about 30 feet northwest of the shaft center and continues beyond. Sample No. 8 of this seam assays 12.40 per cent graphite. Southeast of the shaft, it is shown to exist at least 15 feet in this direction, and sample No. 7 across the seam, as shown in figure 22, assays 11.73 per cent graphite. The crosscut near the end of the northwest drift is barren. The crosscut at the end of the southeast drift, however, though barren to the southwest, enters a mass of graphitic material some 10 or 15 feet northeast of the drift and passes through 25 feet of the crystalline material.
>
> A first and second drift on this ore, as shown in figure 22, are also largely on the ore. Samples Nos. 3, 4, and 6, taken in the drifts and crosscut, contain 19.30 per cent, 12.80 per cent, and 16.36 per cent graphite, respectively.
>
> Between the first and second levels, graphitic shale is shown on the northeast side of the shaft; the balance of the shaft, however, is barren.
>
> At the second level, as is shown in short dash lines in figure 22, there is a 20-foot drift running northwest. This drift is on a 2 to 4 foot seam of graphitic shale. Sample No. 2 of this seam contains 13.28 per cent graphite. East of the shaft a drift has been run in 25 feet, the south side and bottom of which are entirely in graphitic shale containing, according to sample No. 1, 10.36 per cent graphite. The width of the seam at this point is not, however, determined. Below the second level, in the 8-foot sump, graphite shale appears on the southwest side, and sample No. 5 shows it to contain 12.50 per cent graphite. The balance of the sump, however, including the bottom, is barren.
>
> * * * * * * *
>
> In addition to this ore in the mine, there are two dumps of ore, taken from the workings lying next the shaft. These I sampled by cutting trenches through them and drawing samples from the sides of the trenches. One, an annular dump, formed to make a walkway for the horse-whim, shows by sample No. 11, 12.20 per cent graphite, and contains according to my measurements about 1,747 cubic feet of loose material, or, according to my determination of specific gravity (see Laboratory tests et seq.), 80 tons.
>
> Another dump, which I estimate to contain 1,800 cubic feet, or 89 tons, contains, according to sample No. 10, 10.47 per cent carbon.
>
> A third dump, which shows practically no value on its surface, and which I was assured contained only waste from the barren portion of the workings, also contained about 1,800 cubic feet, but was not sampled.
>
> To sum up, allowing for inevitable inaccuracies, there are in sight on the property at least 5,500 tons of 12 per cent graphite ore.
>
> * * * * * * *
>
> As the value of graphite in commerce depends not only on the percentage of the pure mineral present, but also on the physical qualities of this mineral, together with the composition of the impurities present, and as the value of graphite, in common with that of any ore, also depends on the economy with which a marketable product can be produced, I have undertaken a number of laboratory tests on the samples which I secured with a view to securing some indication of these points.

A brief description of these tests and their results is as follows:

A general sample was made up of all the samples secured underground, and crushed to pass a 10-mesh sieve. It was assayed and found to contain 14.50 per cent graphite. A portion was separated into various sizes and carefully examined. Flakes of graphite being noted, a series of tests were undertaken to determine the amount and quality of this material. Flaked graphite is largely used in the manufacture of crucibles and receives the highest price of any grade. In order to be classed as such, however, the flakes must be sufficiently large not to pass through a 60-mesh sieve. Accordingly, in making this set of tests, finer material than 60 mesh was first carefully screened out of weighed portions of the general sample, and the balance was washed on a vanning plaque.

These tests indicate that ore containing 14.50 per cent carbon (the assay of the made-up general sample) will yield from 1 per cent to 4 per cent of its weight of flaked graphite containing from 56 per cent to 40 per cent carbon, whose impurities contain less than 2 per cent each of iron (Fe) and lime (CaO)—the most common of the objectionable impurities for crucible manufacture.

After taking out the flaked graphite, the residues were crushed to pass the 60-mesh screen, and added to the fines which had originally passed through it. These were then also washed on a vanning plaque, and results were produced indicating that fine graphite could be produced amounting to from 27 per cent to 28 per cent of the original ore and containing from 29.75 per cent to 25.80 per cent pure graphite, the total recovery of graphite in the form of flake and fines being 60 per cent to 61 per cent of the total graphite in the original sample.

Another series of tests of a similar nature was then made on a selected specimen of the ore representing a class which I am inclined to think could readily be secured on a practical scale by hand sorting. This specimen contained the graphite in nodules of more or less pure mineral and showed, on assay, 21 per cent carbon. It was found to contain practically no value in flake graphite, but yielded a product amounting to 31 per cent of the original, containing 37 per cent carbon. This represents a recovery of 55 per cent carbon in the specimen.

A third set of tests was then made on a specimen of the graphite shale, which also could be very readily secured in practice by itself. This was found, on assay, to contain 16 per cent carbon, and yielded on vanning no flake, but a product representing 55 per cent of the whole, containing 24 per cent carbon. This represented a total recovery of 81 per cent of the carbon present in the original.

A fourth series of tests were made on the sample taken from the Lyman lot, which it will be recalled contained 15.27 per cent carbon. It yielded 1.44 per cent of the original as flake graphite containing 42.40 per cent carbon, and 21.8 per cent of fine material containing 40.40 per cent carbon. This represented a recovery of 61.6 per cent of the carbon present in the original.

Experiments were also made to determine the effect of bolting the fine product of vanning through 200-mesh bolting cloth, the vanned, graphitic material having first all passed 100 mesh. Before bolting the sample contained 25.80 per cent pure graphite. Twenty-two per cent of this material failed to pass through the 200-mesh bolting cloth, and was found to contain 41.30 per cent carbon. The balance was either passed through or lost in extremely fine dust and in the mesh of the cloth.

In order to estimate the tonnage of ore in the dumps at the shaft collar, a series of determinations of the specific gravity of the well-packed crushed ore was made. The average of these on sample No. 11 of the annular dump is 1.482. Of sample No. 10, the other ore dump, 1.591. This gives a factor of 21.6 cubic feet per ton of 2,000 pounds for the former and 20.2 cubic feet per ton for the latter.

To determine the tons of ore in sight underground a series of specific gravity tests were made on some of the specimens of the various classes of ore. The averages of these determinations are as follows:

Specimen No. 1	2.488
Specimen No. 2	2.448
Specimen No. 3	2.598
Average specific gravity	2.511

This gives a factor of 12.8 cubic feet per ton of 2,000 pounds.

When it is understood that much of the territory included in this property has not been adequately tested by surface cuts, it may be seen from these extracts that possibilities exist for the successful establishment of a graphite industry at this point.

About 2 miles south of Llano graphite schists trending in a northwest-southeast direction toward Sharp Mountain may be observed. This vicinity is, perhaps, with the exception of the property just described, the most favorable locality to prospect, though graphite schists do occur at many other localities throughout the region. It must be borne in mind, however, in estimating the graphite content of a given band of schist that a little graphite makes a very striking showing.

The graphite bands are confined entirely to the areas mapped as Packsaddle schist.

MANGANESE.

Five miles north of Llano, on the southeast flank of Horse Mountain, prospecting has been done on what is known as the Griffy manganese deposit. The schists and gneisses at this point strike N. 11° W. and dip 24° SW. Two pits are opened at this locality; the southern one is 15 feet long on the strike and 12 feet wide on the dip. About 2 feet of manganese oxide is exposed in this pit. Quartz is banded with the ore. About 90 feet north on the strike a second pit reveals much leaner material.

Both north and south from these pits at intervals small showings of oxide and silicate may be seen. An examination of the pits shows clearly that the oxide present is a decomposition product formed from the silicates, which are observed in place. Both spessartite (a manganese garnet) and piedmontite (a manganese epidote) may be found in considerable abundance. They are associated with quartz and feldspar in grains, forming layers and probably represent metamorphic equivalents of the original elements in the sediments. A microscopic examination of a specimen showed spessartite garnet intergrown with epidote accompanied by much muscovite and quartz and some magnetite. Decomposition in this vicinity is very shallow, and below the oxidized zone the deposits, because of the silicate nature of the minerals and their discontinuity and leanness, are without commercial value.

An analysis of the Horse Mountain ore, from a report of the Arkansas Geological Survey in 1890, by R. A. F. Penrose, jr., is given below:

Analysis of manganese ore, Horse Mountain, Llano County, Tex.[a]

Manganese	24.60
Iron	3.22
Silica	35.93
Phosphorus	None.
Lime	8.48

In Mason County manganese occurs in somewhat the same manner as at Horse Mountain and has been described in the report quoted.

RARE-EARTH METALS.

The Llano region was visited by Frank L. Hess in 1907[b] for the purpose of studying the rare-earth minerals, and the following notes are quoted from his report:

GENERAL DESCRIPTION OF THE DEPOSIT.

Baringer Hill is located about 100 miles northwest of Austin, Tex., on the west bank of Colorado River, near the western edge of the Burnet quadrangle as mapped by the United States Geological Survey. It is 12 miles north of Kingsland, the nearest railroad point, 16 miles west of Burnet, and 22 miles northeast of the town of Llano. It is a low mound rising above the flood plain of the Colorado and formed by the resistance to erosion of a pegmatite dike intruded in a porphyritic granite.

Few if any other deposits in the world, and certainly no other in America, outside of the monazite localities, have yielded such amounts of the rare-earth metal minerals as Baringer Hill.

The writer visited this region in the latter part of February, 1907, fortunately at a time when Mr. William E. Hidden, who has been largely instrumental in making this locality famous through his contributions to mineralogical literature on the rare minerals found here, was conducting mining operations.

The hill is named for John Baringer, who discovered in it large amounts of gadolinite about 1887. No one in the neighborhood knew what the mineral was, and specimens were sent to a number of places before it was identified. A piece fell into the hands of Mr. Hidden, who at once looked up the deposit and afterwards obtained possession of the property. Meanwhile Mr. Baringer had taken out a quantity of gadolinite estimated at 800 to 1,200 pounds, which was largely picked up and carried off by persons in the neighborhood as curiosities. Some of the choicer pieces, showing crystal form, found their way into various museums. The property is now controlled by the Nernst Lamp Company, of Pittsburg, Pa., and is worked by that concern for yttria minerals. Since its acquirement by this company a considerable amount of work has been done on the deposit, consisting mostly of open cuts around the edge of the pegmatite, reaching a depth of 30 or 40 feet. A large block, 30 feet in height and more in diameter, consisting mostly of quartz, is left standing in the middle.

* * * * * * *

Baringer Hill * * * is a small mound which, before mining was begun, rose, perhaps, 40 feet above a surrounding flat, was about 100 feet wide, and from 200 to 250 feet long. The longer axis runs east and west and is nearly at right angles to the course of the Colorado River at this point. The country rock is a coarse porphyritic granite with feldspar phenocrysts about 1 inch long. This granite seems to weather and erode rather easily, and the river has cut a flood plain perhaps one-fourth of a mile wide at this point, while the dike, owing to its greater hardness and freshness, has better withstood the erosion. The pegmatite, an unsymmetrical body with irregular walls, is intruded into the granite in what seems to be a pipe or short dike.

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[a] Penrose, R. A. F., jr., Manganese: Ann. Rept. Ark. Geol. Survey for 1890, vol. 1, 1891, p. 447.

[b] Minerals of the rare-earth metals at Baringer Hill, Llano County, Tex.: Bull. U. S. Geol. Survey No. 340, 1908, pp. 286-294.

At the edges of the intrusion is a graphic granite of peculiar beauty and definite structure, being more like the textbook illustrations than the usual graphic granite found in the field. The altered band is from 1 foot to 5 or 6 feet thick and apparently surrounds the pegmatite. No segregation of the feldspar or quartz in particular parts of the dike can be noted, except that the feldspar may possibly be more inclined to occupy the sides of the intrusion. As far as shown it occupies most of the western and southern sides, and the quartz occupies the center and much of the eastern side.

One quartz mass is more than 40 feet across. The quartz has distinct white bands, from one-eighth to one-half inch wide, which seem to be due to a movement akin to flowage and are similar to those found in many pegmatitic masses in other portions of the country. The white banding is due to small liquid inclusions, many of them containing bubbles which either do not move from change of inclination of the fragment containing them, or do so but slowly. The cavities are minute, largely of irregular, angular shapes, suggesting at first glance particles of broken minerals, and occur in straight or broken lines that probably follow fine cracks which were later cemented. Groups of these cracks, with their inclusions, form the bands, which seem to lie approximately parallel to the walls of the dike or at such angles with them as might easily be formed by the flowage of the material into the space it occupied in the granite. The condition of the quartz seems to show that the pegmatite, after being forced into the granite, partly cooled and solidified and then made another small movement, or a series of slight movements, at which time the minute fractures were formed in the quartz and the magmatic fluids were forced into them, but as the mass was not yet totally solidified the cracks were effectually healed and the fluid was inclosed. Such movements may be supposed to have been consequent on the readjustment of the mass on cooling. Between the fracture bands the quartz is glassy and clear. At one place a vug was found large enough for a man to enter, lined with "smoky" quartz crystals reaching 1,000 pounds or more in weight. This would seem to indicate that the pegmatite had been intruded in a pasty or semifluid condition and that the vugs represent the spaces occupied by segregated water that was squeezed from the magma as the minerals took their final solidified form.

The feldspar is an intergrowth of microcline and albite, of a brownish flesh color, beautifully fresh, and occurs (1) in large masses reaching over 30 feet in diameter, and (2) as huge crystals, many of which, though they rarely show terminal planes, have one or more sharply defined edges, especially where partially surrounded by quartz. An edge 34 inches long was measured on one crystal thus embedded. A smaller crystal was seen which was about a foot long, weighed perhaps 20 pounds, and showed fine terminations and twinning planes.

A large amount of feldspar has been mined and thrown on the dump, and it is possible that in time the dump material may be utilized, either for its potassium content, as a fertilizer, or for pottery making.

Large crystals of fluorspar, measuring a foot along the edge, occur in the quartz, but this mineral does not form any considerable percentage of the mass. The fluorspar ranges from almost colorless to violet so dark that it is practically opaque. Where found alone in the quartz it was, so far as observed, of lighter color than where found with dark-colored minerals. Mr. Hidden informed the writer that it sometimes becomes luminous at the temperature of a living room.

Ilmenite occurs in radiating bunches of sheets or blades ranging from 1 inch to 10 or 11 inches in width and from one-sixteenth to one-fourth of an inch in thickness. In cross section the ilmenite looks like the ribs of a fan, with the outer ends from one-fourth to three-fourths of an inch apart. Similar aggregations take different angles, and numbers of such groups are found lying close together. With them occurs biotite mica in like bunches, the sheets of which are said to reach 3 feet in width by an inch in thickness. The mica is reported by Mr. Hidden to contain cæsium and rubidium, and to be close to lepidomelane in constitution. Small flakes of lithia mica reaching half an inch in diameter are found, generally along cracks in the quartz. No muscovite was seen, but it is said to be found occasionally. Compared with the mass the total amount of mica is very small.

THE RARE-EARTH MINERALS.

The greatest interest in the dike centers in the accessory minerals, particularly in the occurrence of the rare-earth metal minerals, which, as stated, probably have never been found at any other place in such large masses and in such quantities as in this locality. So far the excavations are comparatively shallow, and such minerals as are found are more or less weathered. Many show their crystalline form, but owing to alteration the crystals are now imperfect.

Allanite, a variable silicate of calcium, iron, aluminum, the cerium metals (cerium, praseodymium, neodymium, and lanthanum), and in smaller amount those of the yttrium group, occurs in large masses, one of which weighed 300 pounds and was embedded in purple fluorspar. It is a dense black mineral with a fine luster, and a hardness of about 6. Around the edges and along cracks it shows alteration to a brown substance having a hardness of about 5.5. The percentage of yttria ordinarily occurring in allanite is small and rarely exceeds 2½ per cent.

Cyrtolite is rather common in the dike in peculiarly fine, polysynthetic groupings with curved faces. It is brown on the surface, with a darker or nearly black interior, and is evidently a mixture of substances. It carries a considerable amount of zirconia and some yttria, and is supposed by Mr. Hidden to be an alteration product of zircon. If it is such a derivative, the original mineral was probably much more complicated than ordinary zircon. It makes a fair radiograph, which also gives evidence of its nonhomogeneity.

Fergusonite, a variable columbate of the yttrium group and other of the rare-earth metals, occurs in four varieties, so different as to be almost distinct minerals. The difference between them is due to oxidation and hydration. No anhydrous varieties are found. It is found in crystalline form surrounded by decomposition zones. Bunches of irregular crystals have been broken out, weighing over 65 pounds. It is generally a mixture of minerals, as may be easily seen on a smooth surface from the different colors. The difference in composition is strikingly shown in a radiograph, the variations being marked by difference in radiation. According to the two analyses by Hidden and Mackintosh,[a] the fergusonite obtained here carries from 31.36 to 42.33 per cent of yttria and accompanying rare-earth metals, and 42.79 to 46.27 per cent of columbium dioxide. The two analyses give 1.54 per cent and 7.05 per cent of uranium oxides. These are probably very irregularly distributed through the material, as shown both by the mineral itself and especially by its radiographs, which are of striking beauty.

Gadolinite, a silicate of beryllium, iron, and yttrium, is the most important of the minerals found here. It contains about 42 per cent of the yttrium oxides, with a molecular weight of 260, and occurs in crystals and masses of irregular shape up to 200 pounds in weight. The outer portion of the mineral and that adjacent to the cracks is altered to dense brick-red material, but the mineral itself is of a fine, glassy black, with a smooth conchoidal fracture. Thin splinters are bottle-green in color.

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[a] Hidden, W. E., and Mackintosh, J. B., Yttria and thoria minerals from Llano County, Tex.: Am. Jour. Sci., 3d ser., vol. 38, 1889, pp. 483–484. The minerals of this locality have been well described by these writers in a number of papers.

It has a specific gravity of a little over 4.2 and a hardness of 6.5 to 7. A specimen collected makes no impression on a photographic plate with 50 hours' exposure.

Polycrase, a columbate and titanate of yttrium, erbium, cerium, and uranium, occurs in grains, small masses, and plates, the last associated with ilmenite in such a manner as to suggest the probability of replacement. It normally contains between 20 and 30 per cent of yttrium oxide, but is in too small amount to be commercially important. It is very radioactive and quickly affects a photographic plate.

Other rare-earth metal minerals found in the dike are yttrialite, rowlandite, nivenite, gummite of several varieties, thorogummite, mackintoshite, and tengerite. These minerals are apt to occur in any part of the dike, either in the quartz or the feldspar, but have so far been found mostly along the outer portions. A peculiarity of their occurrence is that they are found in bunches from which, if in quartz, radial cracks extend in every direction, and by following such cracks the minerals are found. An illustration of such an occurrence was published by William E. Hidden in 1905.[a] The cause of these "stars," as they have been called by Mr. Hidden, is not clear, but the thought suggests itself that the rare-earth metal minerals may have crystallized first from the magma and the solidifying quartz, being unable otherwise to accommodate itself to the incompressible nucleus cracked in this manner.

Mr. Hidden stated that in mining one of the largest pockets the faces and hands of himself and his assistant were affected as if by sunburn, and, as in sunburn, the covered flesh was not irritated. He suggested radioactivity as the cause, and inasmuch as the minerals under consideration are radioactive, the explanation seems plausible.[b]

The following was given by Mr. Hidden in a personal communication as a complete list of the minerals found in Baringer Hill:

Minerals found in Baringer Hill, Llano County, Tex.

Silicates.

Albite; } occur as intergrowths making up the mass of the feldspar.
Microcline; }

Allanite; a variable silicate of calcium, iron, the cerium metals, and less amounts of the yttrium group, in masses weighing up to 300 pounds, embedded in purple fluorspar.

Biotite; close to lepidomelane.

Cyrtolite; hydrated silicate of zirconium, yttrium, and cerium. Radioactive, abundant.

Gadolinite; a silicate of beryllium, iron, and yttrium in masses weighing up to 200 pounds.

Lithia mica; apparently a later deposition in cracks in quartz. Small flakes one-half inch or less across.

Orthoclase; not abundant.

Yttrialite; an anhydrous silicate of thoria, yttrium, and cerium earths. Contains about 30 per cent silica, 46 per cent yttria, 10 to 12 per cent thoria, and 5 to 6 per cent ceria. Does not occur in large quantity.

Rowlandite; practically a hydrated yttrium silicate. Contains 5 per cent fluorine.

Columbates.

Fergusonite; four varieties, due to oxidation and hydration. Neither is anhydrous. Purest, 5.65 specific gravity. So different as to be almost distinct minerals. Crystals surrounded by decomposition zones.

Polycrase; columbate and titanate of yttrium, erbium, cerium, and uranium. Contains about 25 per cent of yttria.

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[a] Some results of late mineral research in Llano County, Tex.: Am. Jour. Sci., 4th ser., vol. 19, 1905, p. 432.

[b] Mr. Hidden has described this incident in the article referred to.

Oxides.

Hematite; specular, small quantity.

Magnetite; without metallic acids or rare earths.

Ilmenite; iron-titanium oxide in beautiful crystals, as well as plates up to 8 or 9 inches broad.

Rutile; titanium oxide, in prismatic and reticulated forms one-fourth inch thick.

Quartz; large masses and crystals of white quartz and "smoky" crystals up to 1,000 pounds in weight. Amethysts of gem quality reach 1 inch by one-half inch.

Uranates.

Mackintoshite; 3 parts thorite to 1 part uraninite; contains 13 per cent silica and a small amount of yttria. Radioactive; several times more so than its alteration product.

Thorogummite; formed from mackintoshite by addition of H_2O and alteration of UO_2 to UO_3.

Nivenite; a uranate of uranium, thorium, yttrium, and lead. Contains 10 per cent of lead. The most soluble uranate yet discovered; soluble in 5 per cent solution of SO_3. Prints well and gives great detail. Occurs in cubes and masses. (See Dana's System of Mineralogy, p. 889, for two analyses.) Alters to gummite.

Gummite; several varieties.

Phosphate.

Autunite; hydrous phosphate of uranium and calcium; secondary, not analyzed.

Carbonates.

Tengerite; carbonate of yttrium and beryllium. Generally globular, but occurs also as crystals up to one-sixteenth inch in length singly and as little nests. May be a mixture of beryllium and yttrium carbonates.

Lanthanite; carbonate of lanthanum, containing also cerium, praseodymium, and calcium. In incrustations on allanite.

Sulphides.

Chalcopyrite; iron-copper sulphide, massive, in small amount.

Pyrite; iron sulphide, cubic and octahedral.

Sphalerite; zinc sulphide; the purest fergusonite contains some zinc.

Molybdenite; molybdenum sulphide in scales 5 inches wide, which form masses weighing up to 10½ pounds. Alters to powellite.

Molybdate.

Powellite; calcium molybdate, in white crusts lining cavities where MbS has been. Sugary white radiating or plumose crystals, one-fourth to three-fourths inch long. Locally greenish.

It is interesting to note that among the numerous minerals in this dike no tourmaline, zircon, beryl, monazite, cassiterite, garnet, or tungsten minerals have been found. Cassiterite has been reported from the neighborhood, but its occurrence is extremely doubtful.

With the exception of the alteration products and probably of the lithia mica, which as noted, occurs along cracks in the quartz, all the minerals are believed to be original constituents of the dike.

The possibility of finding dikes having a like variety of minerals at once suggests itself, and much prospecting has been done for them. A few specimens of the rare-earth metal minerals have been found at other places in the neighborhood, but only a few, and in small quantity. However, similar dikes occur, as already stated, and these have not all been thoroughly investigated. It is to be remembered that these minerals form but a small fraction of 1 per cent of the mass, and it might easily happen that comparatively large amounts could exist in a dike and not be exposed at the outcrop. They are minerals which are altered to softer products by exposure, and would thus be easily removed by erosion and weathering. The cracks surrounding nuclei of the minerals should be useful in prospecting.

ECONOMIC VALUE.

The economic interest in the rare-earth metal minerals centers in their incandescence on being heated, and owing to this property they have been much sought. Thoria, beryllia, yttria, and zirconia show it in the greatest degree. It was found, however, that thoria and beryllia, which form the bulk of the incandescent oxides used in gas mantles, are too easily volatilized to be used in an electric glower, such as that of the Nernst lamp. Yttria and zirconia, however, will stand the necessary high temperature. Up to the discovery of this deposit it was practically impossible to get sufficient yttria-bearing minerals to manufacture the lamps, but fergusonite and gadolinite, with lesser amounts of cyrtolite, are found here in large enough quantity to meet the requirements. The zirconia is obtained from zircon brought from other localities.

In the manufacture of the glowers for the Nernst lamp, a paste consisting of 25 per cent of yttria and 75 per cent of zirconia is squirted into strips of the proper thickness, baked, and cut into the required lengths. When cold the mixture is nonconducting, but after being heated it becomes a conductor and gives a brilliant light.

The needs of the Nernst Lamp Co., which owns the deposit, require only the occasional working of the mine. After enough yttria minerals are obtained to supply its wants for a few months ahead, the mine is closed. But a few hundred pounds per year are extracted.

Rare-earth minerals have been noted at several localities besides Baringer Hill.

Professor Hidden mentions the discovery of two crystals of gadolinite about a mile south of Baringer Hill. Several pounds of allanite were taken from a mass of pegmatite outcropping as a low knoll about 2½ miles west-northwest from Kingsland, near Williams's garden. Fluorite occurs with the allanite at this place. The amount of prospecting is practically negligible.

In Burnet County, 2 miles due east of Baringer Hill and about one-half mile west of Shiloh Church, is another gadolinite locality. The matrix rock is like the pegmatite of Baringer Hill, but the mass is obviously smaller. The old workings consist of a shallow trench from which a few tons of pegmatite have been removed.

All the above-mentioned localities are in the area of coarse red granite. Outside of the granite area only one locality came under observation. Near the east side of Mr. Dorbant's pasture, south of the Burnet-Bluffton road, small masses of weathered rare-earth minerals are to be found in irregular narrow dikes of pegmatite inclosed in dark schists. This locality is about 4½ miles from Colorado River and 7 miles from Burnet.

ZINC BLENDE WITH FLUORITE GANGUE.

Deposits of fluorite carrying irregular amounts of metallic sulphide minerals occur at two localities west of Burnet within the drainage basin of Spring Creek. A fluorite-bearing reef has been opened on the Bailey place, about 4 miles from Burnet and a mile west of the Bluffton road. In this vicinity the rocks are pre-Cambrian gneisses and schists cut by minor masses of granite and pegmatite. Structural trends are east and west, the rocks, though poorly exposed, being evidently complexly folded. The outcrop of the fluorite reef is on top of a ridge between two of the upper tributaries of Spring Creek. The bulk of the rocks adjacent are feldspathic gneisses, but with these are interlayered masses of hornblende schist. Locally the strike of the different layers is about N. 60° E., and dips are to the southeast.

A mixture of fluorite and hornblende with a little quartz, feldspar, and chalcopyrite occurs in the form of a layer inclosed by light-colored gneiss. The material carries scattered grains of galena.

The deposit was prospected several years ago by means of a shaft and nine shallow excavations. A line joining the several openings trends N. 60° E. From what could be made out in 1909, it appears that fluorite was found along the strike of the layer for a distance of nearly 300 feet. On the southwest the mineral was encountered in five trenches, showing an extent along the reef of 100 feet. Counting toward the northeast, trench No. 5 shows a bunch of mineral which seems to represent the bottom of a shallow trough, as gneiss is exposed on both sides and below it. The next trench lies 135 feet northeast of No. 5. Here there is no evidence of the reef and the intervening ground is completely covered. However, about 40 feet farther on is the shaft, about which is piled a considerable amount of fluorite rock. This shaft contains water within about 20 feet of the surface. Its lower portion is evidently in feldspathic gneiss.

About 15 feet northeast of the shaft is a pit sufficiently deep to expose 20 feet of the fluorite-bearing layer measured down the dip, the dip being less than 10° SE. Thirty feet beyond, another excavation appears to have revealed no mineral, and the same is true of a long trench 325 feet northeast of the shaft. All the fluorite from this locality is white.

The purest masses of the mineral appear in the southwesterly pits, where the reef averages perhaps less than a foot in thickness. In the part adjacent to the shaft on the northeast, the reef has a maximum thickness of 2½ feet, but pinches and swells to a marked degree. Here the fluorite constitutes about 60 per cent by bulk of a granular rock containing hornblende, quartz, feldspar, and a little chalcopyrite. A carefully taken sample of the fluorite rock piled up about the shaft showed on assay a trace of gold and 0.38 ounce silver. Copper was not determined, but from the small amount of chalcopyrite in the fluorite rock this metal can hardly amount to more than 1 per cent.

Fluorite accompanied by zinc blende is found at several points in the upper valley of the north fork of Spring Creek on and near the Frank Thomas place. The locality is about 7 miles west of Burnet. The occurrence of the mineral is in layers conforming with the north and south trending structure of the inclosing dark hornblende schists. About half a mile north of the dwelling house a shaft has been opened to a depth of 25 feet. Here the layer or reef is about 3½ feet thick at the outcrop. The material thrown out of the shaft is a mixture of fluorite sulphide minerals and a little quartz. Zinc blende is the most abundant metallic mineral, but galena, pyrite, and molybdenite may be observed. The assay of a carefully taken sample of the material thrown out of the shaft shows[a] zinc 7.60 per cent; lead, none; gold, a trace; silver, 0.56 ounce.

Whether or not this reef has any degree of continuity along the strike can not be stated, since no adequate surface explorations have been made. In the absence of any assurance of a continuous vein no estimate of the prospective value of this deposit is warranted. It may be said, however, that if only a few thousand tons of 7 per cent zinc ore could be developed there is no apparent reason against the possibility of profitable mining upon a small scale.

In the vicinity of the Thomas dwelling house fluorite has been discovered near the well on the east of the creek bed. The reef, which is not over 10 inches wide, trends north and south and stands nearly vertical. Going south along the strike the mineral has been uncovered in three or four places within a distance of somewhat more than one-fourth mile. At one point a shaft sunk in black schist encountered fluorite and chalcopyrite disseminated in black hornblende schist.

Other outcrops of fluorite were seen south of the eastward-flowing drain one-half mile south of the house.

Some of the fluorite in this vicinity is nearly free from other minerals, but specimens may be found which are made up of nearly equal parts of black zinc blende and fluorite, with a little quartz and a little pyrite. Such prospecting as has been done is not sufficient to demonstrate that these deposits have any promising degree of persistence.

SERPENTINE AND TALC.

Talc deposits have been found at a number of places within the pre-Cambrian rocks and serpentine has been found in a body of considerable size at one locality. Prospecting has been carried on with a view to proving commercial deposits at several places.

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[a] Assay by E. E. Burlingame.

Serpentine.—The Collins property, located 9 miles south of Llano, a little west of the Oxford road, contains about 250 acres lying in a strip about 1½ miles long in a north-south direction. Near the north end of the property and on a hillside is a pit perhaps 20 feet in diameter and 10 feet deep. This pit is in serpentine and exposes on its west side a contact with soapstone. For perhaps 100 feet east and northeast of this pit and for at least 500 feet southeast and south serpentine is exposed.

At the foot of the hill a second pit about 30 feet in diameter by 10 or 15 feet deep exposes serpentine rock. At this point a diamond-drill hole was bored 275 feet deep without passing out of serpentine rock. Over the next pass to the south, serpentine is exposed for 100 feet or more down the slope, and a third pit about 10 feet wide by 20 feet long and 10 feet deep has been opened. Except a small outcrop of schist, the pit exposes only serpentine.

To the west and also partly surrounding these exposures of serpentine are very considerable exposures of soapstone, in which occur veinlets of asbestos and geodes of quartz and amethyst crystals.

It may be seen from the dimensions given above that a considerable deposit of serpentine and talc exists at this locality. Specimens were seen which took a fine polish. The commercial value of such a deposit will depend directly upon the demand that can be created for the serpentine.

Though blasting has been the only method employed in taking out material, blocks of considerable size have been extracted, and if more refined methods are used, there is no doubt that much larger blocks would be quarried and sawn into commercial sizes. An installment to carry on such work on a large scale would involve a considerable investment, and the opening of the property on a small scale would seem for the present more advisable. Market conditions and transportation would need to be carefully considered before any extensive plan of operation were adopted.

The relation of the outcrop of the body above described to the inclosing schist-gneiss series leaves little doubt that the deposit is an alteration product of a pyroxenic or peridotitic intrusive mass. As has been shown in an earlier portion of this report gabbroic and dioritic types of intrusives are present in the region. The presence of quartz and amethyst geodes and the occurrence of iron oxides in connection with the deposit point to the same conclusion; that is, they represent the silica and iron content derived from the breaking down of magnesian iron silicate minerals.

Talc.—Talc is found at a number of localities in addition to that associated with the serpentine deposit already described. In the area immediately east of Cedar Mountain, numerous small outcrops were seen, though in no case was any deposit mapped separately.

A small deposit also occurs 1½ miles west of Llano, and a deposit on which considerable work has been done is located about 1 mile north of Graphite station.

The small deposit west of Llano is formed without doubt by the hydration of magnesian silicate minerals developed by regional or contact metamorphism in pre-Cambrian limestone strata. A small pit is opened on the ledge, but stripping has been insufficient to prove the horizontal extent of the body. The presence of silicate minerals in the talc would destroy its commercial value. This point can only be determined by exploration work. Locally silicate minerals were noted in the material.

The talc deposits east of Cedar Mountain are associated with the dark series of schists described earlier in this report. This locality, however, is exceptional in that considerable bodies of dioritic rocks are intruded into the schist series. The talc in this area is probably in a large measure derived from limestones by the hydration of magnesian silicate minerals. It is almost certain, however, that some of the deposits are due to the alteration of basic intrusives or their equivalents, the amphibole schists. No large deposits of talc were seen in this vicinity, but considering the soft nature of talc and its tendency to break down and be covered up by surface soil, it is suggested that prospecting might reveal commercial deposits.

Surface outcrops do not give much information as to underground conditions at the property located a mile north of Graphite station. The following notes regarding underground developments are abstracted from a private report by William Young Westervelt, to whom part of the underground workings were accessible. The open cut described was poorly exposed at the time of the present writer's visit.

The property contains in all some 980 acres and the openings are all within a few hundred feet of the Houston & Texas Central Railroad. The workings are along a general northwest-southeast course and consist, commencing at the southeast end, of the following openings: A small shaft has been sunk 28 feet, from the bottom of which two crosscuts have been driven in northeast and southwest directions. At the time of visit the northeast crosscut was 13 feet from the center of the shaft. The southwest crosscut was too nearly filled to be accessible, though it was stated to be 9 feet long from the center of the shaft and, like the northeast drift, all in soapstone. The shaft itself was noted to be entirely in soapstone.

At 33 feet northwest of the shaft is an open crosscut 14 feet wide, 14 feet deep at one end, and sloping up in a northeasterly direction to a depth of but a foot or so at its northeast end, 40 feet distant. At the southwest end a schist wall is exposed, but for a distance of about 25 feet from the wall the cut is made entirely in soapstone. This soapstone in the deepest part exhibits considerable solidity, and apparently blocks of some size could be taken from it.

At 83 feet northwest of the first shaft is a second shaft 32 feet deep, but it was inaccessible. The dump consists entirely of soapstone, and it is probable that the shaft is wholly in that material. From the workings described there is good evidence that a mass of soapstone 20 feet wide by 90 feet long by 25 feet deep is present. The horizontal extent of this body can only be determined by more crosscuts and shafts, the outcrop being hidden by the surface mantle of soil.

The successful introduction of this material into the market will depend, first, on the size of the deposit that can be proved to exist, and second, on whether or not the several physical characteristics are present which are necessary in such material to permit competition with quarries operating in the East.

There is very little doubt that the deposit owes its origin to the hydration of magnesian silicate minerals developed in pre-Cambrian limestone by metamorphism. Such an origin would give to the deposit a bedlike character continuous in depth and horizontal extent only in so far as the silicate minerals had been developed and later altered to talc. As this process might result in deposits of great extent or in podlike masses of small size, it follows that exploration by crosscuts and shafts is the only practical method of exploring the deposit.

OIL.

A small oil seepage in a spring near the town of Burnet has deposited at the surface asphaltic material in the cracks and interstices of the neighboring limestones. In Post Mountain, also, a little oily residue is found about 20 feet above the base of the Cretaceous. The beds in which this oily residue is found are very near the base of the Cretaceous system, and consequently only a few feet above the underlying Paleozoic beds. (See geologic map, Pl. III.)

The underlying Cambro-Ordovician limestones, shales, and sandstones have not shown any indication of oil throughout the Llano-Burnet region. The Carboniferous strata of the region, on the other hand, have a decidedly petroliferous odor. Though the Trinity sand at Burnet is deposited on Cambro-Ordovician limestone, it is quite possible that a short distance to the east Carboniferous beds, raised by faulting, may be the basement upon which the Cretaceous sands rest. It is possible therefore that oil has passed from the underlying Carboniferous into the porous Trinity sand and spread laterally as far west as Burnet.

As has been pointed out by Taff and Reed,[a] the Trinity sand is of such character (being a beach or shallow-water deposit of siliceous sand with thin beds of clay) as almost to preclude the idea that oil originated in that formation.

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[a] Taff, J. A., and Reed, W. J., The Madill oil pool, Oklahoma: Bull. U. S. Geol. Survey No. 381, 1910, p. 513.

The lack of other indications of oil in other portions of the Trinity in this region, the structurally broken and eroded condition of the underlying Paleozoic, and the petroliferous odor of the Carboniferous beds point to the conclusion that though a small quantity of oil may have passed upward from below, it is extremely improbable that oil in commercial quantities is present in the Burnet and Llano quadrangles.

STRUCTURAL MATERIALS.

Limestone, sandstone, and granite are present in large quantities in the central Texas region, and in the pre-Cambrian schist series marbleized limestone beds also are found.

MARBLE.

Only a few attempts have been made to utilize the marbleized limestone beds occurring in the pre-Cambrian rocks. A small amount was quarried from an opening near Bachelor Peak and was used in part in the construction of the Llano courthouse. Recently an opening has been made by Messrs. Sellman and Bernard, of Llano, on a marble ledge on the northern edge of the town of Llano. The operators propose to work the deposit, at least at first, on a small scale to supply a local demand for such material.

It may be said in general that much of the marble in the pre-Cambrian is of slight value because of its impurities. It is not improbable, however, that ledges exist of sufficient width and length and of such color and purity that quarry floors could be successfully opened. Such localities can only be found by diligent search, with careful sampling by surface cuts or pits.

The marble is practically all of a fairly coarse crystalline type, more or less mottled blue or black. Some pure white ledges undoubtedly occur, but, taken as a whole, the material represents a common variety of stone and probably will never command a high price. That operations may be carried on at a fair profit, however, at some time in the future is probable.

SANDSTONE.

A sandstone quarry has been operated intermittently for a number of years at a point north of Fairland, Burnet County. A considerable quantity of this material has been shipped out of the county, and the stone is used also in neighboring towns. The quarry is opened in beds of the Hickory sandstone. At this point the material is a light brown, rather fine-grained sandstone. The beds dip gently into the hillside, and bedding planes are prominent and add to the ease with which the stone may be worked. A spur connects the quarry with the Houston & Texas Central Railroad. The demand fo· this stone at the present time is limited, competing as it must with abundant limestone building material at points beyond the Llano-Burnet region.

LIMESTONE.

Portions of the Edwards limestone and certain layers in the Trinity formation can be used for building purposes. The latter beds, of yellowish to white color, are quite easily extracted and in the quarry are often so soft that they may be sawed into blocks. This material becomes harder when exposed to the air.

GRANITE.

Granite forms a considerable proportion of the pre-Cambrian rock of the region. Unfortunately, however, from the viewpoint of the quarryman, all of this material is not available for use. In an earlier part of this report it was shown how the intrusion of granite had locally produced areas characterized by the presence of abundant schist fragments intermixed with the intruding rock. The condition is a very common and unfortunate one, and if it were not that many extensive areas also are underlain by clean stone the quarry industry in this region could have only a decidedly moderate growth. It may be said at once, however, that granting transportation and market, there is available an enormous quantity of clean granite in the region.

Of this material two very distinct types are present—(1) the coarse and very coarse grained granites and (2) the medium to fine grained granites, among which a number of varieties may be distinguished.

Of these two types the former is commonly free from such imperfections as would prevent its use, while the latter is locally marred or spoiled by the presence of schist fragments or iron pyrite.

By a glance at the map (Pl. III, in pocket) it may be seen that an extensive area of very coarse grained rock underlies the territory in southwest Llano County. Practically inexhaustible supplies of this granite lie above what would be railroad grade in the vicinity of Enchanted Rock. A further examination will show that both at Granite Mountain in Burnet County and north of that point are broad areas underlaid by coarse-grained stone. The wide distribution of the fine-grained types may also be seen, but of them it is not possible to predict that any given spot consists of clean granite, for, as explained above, various impurities may be present. In such areas only by careful examination can excellent quarry sites be selected.

A number of quarries have been opened in areas more or less characterized by the presence of schist fragments, and at other localities abandoned quarries were seen where the presence of iron pyrite must have been one of the factors leading to their disuse.

One fact directly dependent upon the geologic relation of the granite to the schists and having a decidedly practical bearing on the selection of quarry sites is this: In areas of mixed schist and granite (that is, where granite has intruded the schists in a complicated way) there can be no assurance that what is apparently an excellent quarry floor will hold its valuable qualities in depth. It is in fact probable that schist fragments will be encountered in such amount as either wholly to ruin the enterprise or to reduce profits to a minimum. It is of course true that the mass may continue clean, but the chance is too small to be worth the risk.

At the present time transportation facilities deeply affect the growth of the granite industry, the Parkinson group of quarries, for example, being so situated that a wagon haul of 6 miles is necessary. The haul for other quarries is as much as 11 miles. A number of quarries, however, have been operated near the railroad, the quarry at Granite Mountain (the most extensive operation in the region), on the Houston & Texas Central Railroad being a notable example.

At the present time, exclusive of that from the Granite Mountain quarry, by far the greater part of the stone quarried is used for monumental purposes. The stone, for example, from the Gootch & Wells quarry, on the Parkinson tract, and from the Norton quarry, 11 miles south of Llano, is a medium to fine grained gray granite, and takes a fine polish. Much of the granite is well suited for large structures and could be so utilized were transportation better and a more active market available.

Granite Mountain quarry.—The Granite Mountain quarry is located on the Houston & Texas Central Railroad at Granite Mountain, Burnet County, near the town of Marble Falls. The owners since 1893 are Darragh & Catterson. Before that date the property was owned by Lacey, Westfall & Norton.

The quarry is opened in the side of a broad, low, bare, granite hill. No stripping is necessary. Sufficient granite is exposed above the present railroad grade to furnish material for a great many years.

The rock is coarse-grained pink granite, consisting of quartz, microcline (dominant), albite-oligoclase, some orthoclase, and biotite. Though portions of the mass are intruded with pegmatite, an enormous quantity of fine material is at hand. A well-defined rift aids quarrying. Sheets of any desirable thickness can be lifted, and facilities for handling impose the only limit to the size of blocks that may be obtained. The greater part of the rock quarried has been shipped in 5 to 10 ton blocks to the Galveston jetty. This work was begun in 1891 and continued to 1898. Little work was done from 1898 to 1902 From 1902 to the present time about 1,000,000 tons of rock were shipped. Before that, however, 2,000,000 tons were shipped, and in addition 120,000 yards of crushed rock have been used on the same work. Probably 2,000,000 tons were used as cap rock.

The capitol building at Austin, begun in 1884 and finished in 1899, and courthouses in Galveston, Houston, and at other localities, are built of this granite. Nevertheless, but a small part of the output has been dimension stone. This class of stone will probably grow in importance.

The quarry is equipped with 20-ton rigging. There are 5 derricks, a 1,500-foot cableway, and a tram. The rock is generally swung direct to the cars. A No. 7½ Gates crusher is also installed. About two-thirds of the labor employed is white. Engineers are paid $2.50 to $3.50 per day; derrick men, $2.75 to $3; foremen, $4; common laborers, $1.50 to $1.75.

Freight rates per ton of rough granite to points in Texas range from $1 to San Antonio to $1.40 to Aransas Pass.

Teich quarry No. 2.—This quarry is a short distance west of Kingsland, Llano County, and is connected by a spur with the Houston & Texas Central Railroad. It is owned by Mr. Frank Teich, of Llano, and was opened in 1908. The rock is a coarse-grained pink granite, and takes a fine polish. The Memorial Church of Orange, Tex., is built of this rock. About 50,000 cubic feet have been extracted, valued at 50 cents a cubic foot. The quarry was not being worked when it was visited.

Mr. Teich operated a small quarry on the Parkinson tract 6 miles south of Llano during the summer of 1909. About 6,000 cubic feet was extracted and manufactured into monuments at Teich's polishing works near Llano. This quarry was abandoned in the summer of 1910. A new quarry, Teich No. 3, is being opened about 4 miles south of Llano on Mr. Sheeon's land.

Gootch & Wells quarry.—Gootch & Wells are operating a quarry on the Parkinson tract about 6 miles south of Llano. The quarry presents a very rough and irregular appearance. The pit is from 25 to 50 feet deep and about 150 long in an east-west direction. About 100 feet wide at the east end, it narrows to 15 or 20 feet at the west end. The rock lies in somewhat irregular sheets broken by vertical joints. N. 50° E. is the easiest break.

The following section will give an idea of the sheeting:

Section showing sheeting in Gootch & Wells quarry, Llano County, Tex.

	Feet.
Top ledge, not used (low dip northwest)	5–10
Rotten granite	1– 2
Thick ledge	12±
Rotten seam	½
Ledge	8
Ledge	4

The thickness of the sheets varies considerably, and the presence in parts of the quarry of pegmatite and schist inclusions spoils much rock. The stone is a beautiful gray granite, somewhat resembling the Barre, Vt., stone. It consists of quartz, microcline feldspar with a little albite-oligoclase and orthoclase feldspar. Biotite in small flakes is the dark mineral. The quarries are equipped with 4 derricks, gasoline engines, and 5 air drills. Plug and feathers are largely used for breaking on the finish work. The quarry can produce 250 cubic feet per day.

The granite is hauled to the Houston & Texas Central Railroad at Llano in wagons at a cost of 15 cents per cubic foot. Freight on rough stock varies from 50 cents to $2.50 per ton within the State limits. From Llano to Houston the rate is $1.45. The entire product of the quarry is used for monumental work. The actual cost of quarrying is about 40 cents a cubic foot, varying with the nature of the seams in the quarry. The rough stone is sold from the quarry. Dressing costs from $1 to $25 per cubic foot, according to the nature of the designs.

The best quality of stock sells for $1.50 a cubic foot, this grade being used for best polished work. The cheapest stock used for hammered work sells for 90 cents per cubic foot.

The quarry produced during 1908 about 18,000 cubic feet and will produce during 1909 about 22,000 feet. The entire Parkinson tract produced during 1908 (including quarries operated by Messrs. Patterson, Blodgett, Leiter, and Teich) about 33,000 feet.

Norton quarry.—The Norton quarry, owned by Mr. Norton, of Llano, is located about 11½ miles southwest of Llano and about 3½ miles a little east of south of Sixmile post office. The quarry pit is nearly rectangular and measures 95 feet long in a north and south direction. It is about 35 feet wide and 12 to 15 feet deep. Natural walls, caused by small north and south seams, make the west and east sides. The north end, trending N. 60° E., is a very straight break. The rock breaks easiest the "capping way," while north-south and east-west breaks are about the same in this respect. The stone is a bluish-gray, fine-grained granite composed essentially of quartz, and microcline feldspar, with a little albite-oligoclase and orthoclase. The dark mineral is biotite mica in fine flakes. A little chlorite is present. Pyrite was noted, occupying almost invisible seams; it is not abundant, however, though some fine blocks are spoiled by its presence. Schist fragments also spoil some of the rock. The plant includes 2 derricks and a horse winze.

Stewart quarry.—E. L. Stewart, in August, 1908, opened a new quarry near the old Stewart quarry, about 10½ miles southwest of Llano and about 2½ miles a little west of south of Sixmile post office.

The rock is a fine-grained gray granite. Pyrite is very abundant in parts of the old Stewart quarry near by and may also interfere with the new opening. Schistose material is included in much of the granite of the vicinity and this fact, combined with the presence of pyrite and the long haul to the railroad will probably prevent extensive developments. Two carloads have been shipped to San Antonio and Paris markets, principally for monumental purposes. The rock is hauled for 25 cents a cubic foot loaded at quarry and unloaded at Llano. Quarrymen receive from $2 to $2.50 per day.

Other quarries.—Mr. Bradshaw has opened a small quarry one-fourth of a mile west of the Gootch & Wells quarry. Only the top rock has been removed over a small area.

Mr. H. P. Bailey is also opening a quarry three-fourths of a mile north of Bradshaw's. Only a few cubic feet of rock have been quarried.

Mr. George Patterson is operating a quarry on the Parkinson tract south of Llano, but no notes are at hand covering the operations.

A number of quarries have been worked in the past, but are, for the present at least, abandoned. Such are the Town Park quarry north of Llano, where pyrite marred a very beautiful coarse-grained gray granite porphyry; the Kansas City quarry, 2 miles west of Llano on the Mason road, and the quarry 7 miles northwest of Burnet, where a very dark gray, slightly gneissoid granite has been quarried.

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 451

RECONNAISSANCE
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RECONNAISSANCE OF THE ORE DEPOSITS IN NORTHERN YUMA COUNTY, ARIZONA.

By Howland Bancroft.

INTRODUCTION.

AREA EXAMINED.

The area examined in the reconnaissance here reported is shown on the accompanying general geologic and topographic map (Pl. I). It lies between meridians 113° 16′ and 114° 30′ west longitude and between parallels 33° 30′ and 34° 30′ north latitude, including parts of Yavapai, Maricopa, Mohave, and Yuma counties, Ariz., by far the largest part of the area lying in Yuma County. (See fig. 1.) The investigation therefore covered principally the economic geology of northern Yuma County. Brief mention is also made of the geology and ore deposits of the extreme southeastern part of San Bernardino County, Cal.

PURPOSE AND CHARACTER OF RECONNAISSANCE.

The field work in this area was begun by the writer early in March and completed late in May, 1909. The investigation was a reconnaissance of a large area concerning which little information was available. The object of the work was to get as accurate an understanding of the economic geology of the principal ore deposits of the region as was obtainable in the short time allotted. In the course of the work a few of the most prominent properties were studied in some detail and a great many others were visited. The fact that one property is treated at length and another is apparently hurried over is not necessarily a reflection on the one which received less time and study. The presence or absence of supplies influenced or determined the amount of time which could be spent at some of the camps.

The size of the area examined (approximately 5,000 square miles) and the brief period spent in the field were not the only features adverse to thorough work. The country is very sparsely settled; the lack of development work on many of the properties restricted observation to the surficial phase of the ore deposits; at a great number of the deposits no one was found from whom reliable data could be obtained; and the neglected conditions which exist in many of the camps, where only annual assessment work is done to hold the claims, also interfered seriously with the investigation.

ACCESS TO THE AREA.

A branch line of the Santa Fe system, the Arizona and California Railroad, runs through the center of this area, connecting Wickenburg on the Santa Fe, Prescott and Phoenix Railway with Parker, where the Arizona and California Railroad[a] crosses Colorado River to tap the main Santa Fe line at Cadiz, Cal. At the time of this investigation this railroad was running passenger trains daily and three freight trains weekly between Parker and Prescott. To reach most of the mines rather long trips must be taken from the railroad stations, and these journeys are most frequently made in wagons along stage

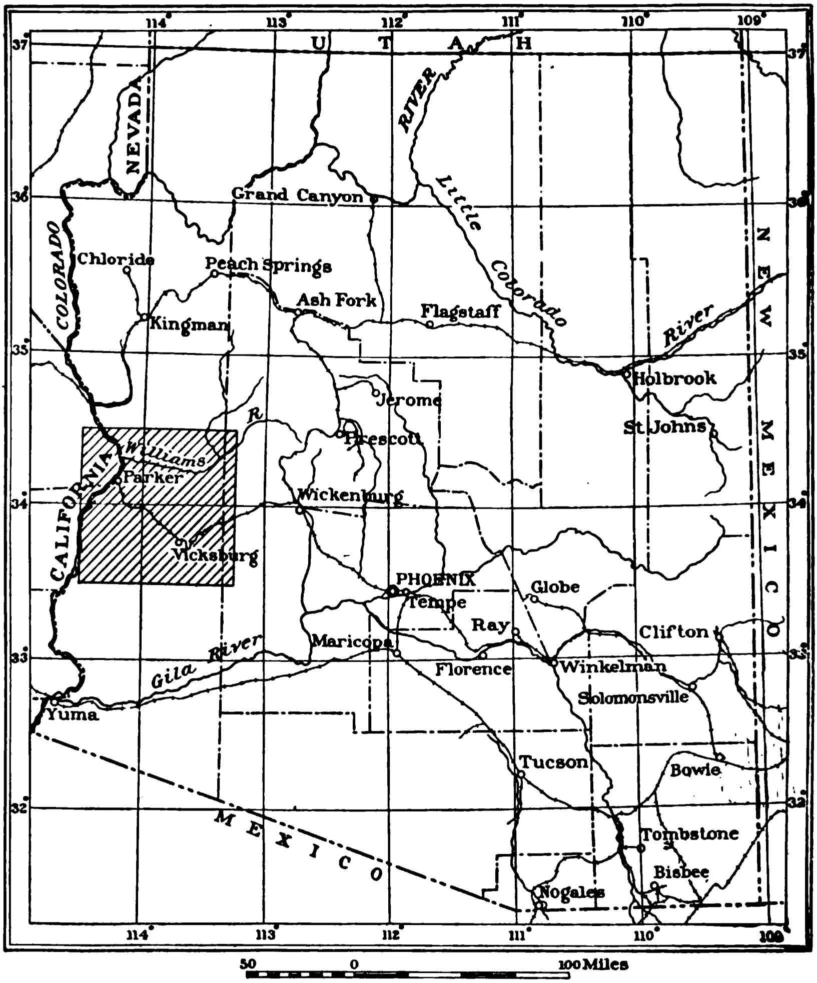

FIGURE 1.—Index map of Arizona showing location of area described.

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[a] This road is now (October, 1910) known as a part of the Santa Fe, Prescott and Phoenix Railway. ily passenger and freight trains run over this line between Phoenix, Ariz., and Los Angeles, Cal.

routes, although on some routes automobiles have been installed.[a] A schedule of these stage lines can be obtained from any agent of the Santa Fe system. Most of the wagon roads are fairly good and there are enough watering places to make travel over almost any part of the region possible, although in some places not at all convenient.

EXPLANATION OF THE GENERAL MAP.

The accompanying general map (Pl. I, in pocket) was originally drawn in the field as a means of locating the mountain ranges and some of the principal prospects and mountain peaks. At first only the boundaries of the several isolated ranges were drawn, the elevations of some prominent peaks were determined by vertical angles, and the locations of the properties visited were noted. The original scale was 4 miles to the inch, the Arizona and California Railroad maps having been utilized as a base and tied in by the latitude and longitude of Monument Peak, furnished by the topographic branch of the United States Geological Survey. After the writer returned from the field, as the Parker sheet was finished, it was decided to reduce parts of the Parker map to the scale of the reconnaissance sheet and to project contours which would extend over the rest of the area examined. The result is a crude topographic map of the district, with 500-foot contours. It is hoped that these contours do not go very far astray in representing the general topography of this part of the territory, and at the same time the users are warned not to expect too much detail in a map prepared in this way and on a scale so small.

The geologic boundaries have not been definitely represented, for they are in few places known to the writer. General conceptions of the geology, however, can be obtained from the map, which admittedly has many faults, most of them due to the reconnaissance nature of the investigation. Rocks supposed to be pre-Cambrian are all represented by one color, regardless of the complex to which they belong. The granite intrusion in the southwestern part of the Harquahala and Harcuvar ranges is mapped in places, although no doubt there are many other exposures of the rock in the area. The lava flows and some of the material supposed to have accompanied them are represented by one color. Valley filling and various detrital deposits are mapped as one formation.

ACKNOWLEDGMENTS.

During the investigation the writer was visited in the field by Mr. Waldemar Lindgren, who spent several days with him examining the geology and ore deposits in parts of the district, and whose conception of the general geologic conditions existing in this region, combined with a great deal of cheerful and generous assistance in the office, has greatly aided in the preparation of this report.

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[a] The Arizona and Swansea Railroad is now (October, 1910) in operation and runs a mixed train between Bouse and Swansea three times a week.

The writer takes this opportunity to express his gratitude to all the mining men of the district, who gave him most hearty cooperation, and especially to Mr. Louis B. Carr, of Wendendale, Ariz., who very kindly offered material assistance and even his own personal services to further the work. To Mr. W. A. Drake and others of the Santa Fe, Prescott and Phoenix Railway Company cordial thanks are due for the use of their maps and for many courtesies.

PREVIOUS INVESTIGATIONS.

With the exception of areas surveyed in a hurried reconnaissance trip made by Lee[a] in 1903, in an investigation of the water resources of a part of western Arizona, only a very small part of the region considered in this report had been examined by the United States Geological Survey prior to this investigation. A part of the northeastern portion of the area was covered by the Wheeler Survey in the early seventies, and the topographic survey of the Parker quadrangle, forming the northwestern portion of the region covered by this reconnaissance, has been completed very recently.

Sundry localities have been examined in a more or less cursory manner by many mining engineers and geologists, and a few of the properties have been carefully studied by competent men, but as the work has been done for mining companies with a view to sale or purchase, the geologic results of the investigations have seldom been made public.

Numerous articles on the general activity, mineral production, and mining interests of this region and its vicinity were published during the years 1869 to 1876 in R. W. Raymond's reports on mining statistics west of the Rocky Mountains, and these reports afford a fund of data on the early history of the region.

Until very recently this region has lain quite out of the ordinary routes of travel and has been without any kind of railroad facilities, so that little information has been published concerning its mines and mining industries. E. A. Haggott, in 1909, prepared a map of the district which shows in a general way the location of the different properties and the principal physical features in the area. The following is a chronological bibliography of papers or reports which deal with parts of this area.

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[a] Lee, W. T., Bull. U. S. Geol. Survey No. 352, 1908.

BIBLIOGRAPHY.

1865. Blake, W. P., Iron regions of Arizona: Am. Jour. Sci., 2d ser., vol. 40, 1865, p. 388.
Describes the geology and iron deposits near Williams River.

1868. Browne, J. Ross, Mineral resources of the States and Territories west of the Rocky Mountains.
Various notes on several mining districts within the area, with brief accounts of the Cunningham, Planet, and La Paz deposits.

1871–2–3. Wheeler Atlas, sheet No. 75.
Shows part of the geology in the extreme northeast of the area investigated.

1871. Raymond, R. W., Mining statistics west of the Rocky Mountains, pp. 267–269.
Contains several notes on various properties in the district.

1872. Raymond, R. W., Mining statistics west of the Rocky Mountains, p. 336.
Contains very brief mention of La Paz district.

1873. Raymond, R. W., Mining statistics west of the Rocky Mountains, p. 312.
Mentions briefly Planet and Constancia properties.

1874. Raymond, R. W., Mining statistics west of the Rocky Mountains, p. 344.
Contains very brief mention of La Paz and Williams Fork districts.

1875. Raymond, R. W., Mining statistics west of the Rocky Mountains, p. 395.
Mentions the McCracken mine.

1875. Wheeler Survey, vol. 3.
Contains a few general notes applicable to parts of the region under investigation.

1876. Raymond, R. W., Mining statistics west of the Rocky Mountains, pp. 351, 353.
Contains notes on the McCracken and Ehrenberg districts.

1877. Hodge, H. C., Arizona as it is.
Describes the Planet and McCracken mines at some length and gives various notes on other districts.

1884. Hamilton, Patrick, The resources of Arizona.
Notes on several of the mining districts.

1893. Blandy, J. F., Some notes on the geology of Arizona: Eng. and Min. Jour., vol. 56, 1893, pp. 473–474.
Geology in the vicinity of the junction of Santa Maria and Williams Rivers.

1899. Blake, W. P., in Report of the Governor of Arizona to the Secretary of the Interior.
Gives notes on the mining districts, climate, and vegetation in the area.

1901. Comstock, T. B., The geology and vein phenomena of Arizona: Trans. Am Inst. Min. Eng., vol. 30, 1900, pp. 1038–1101.
Describes the general geology and vein formations of parts of Arizona, and gives a few brief general notes on properties covered by this investigation.

1902. Pratt, J. H., Gold deposits of Arizona: Eng. and Min. Jour., vol. 73, 1902, pp. 795–796.
Describes the geology and ore deposits of the Socorro gold mine, near Harrisburg.

1903. Austin W. L., Discussion of a paper by W. H. Weed, Ore deposits near igneous contacts, in Trans. Am. Inst. Min. Eng., vol. 33, 1903, pp. 1070–1077.
Brief reference to Planet mine.

1903. Blake, W. P., in Report of the Governor of Arizona to the Secretary of the Interior.
Gives information pertaining to the geology, ore deposits, and localities of several of the more prominent mining districts in the area.

1904. McCarn, H. L., The Planet copper mines: Eng. and Min. Jour., vol. 78, 1904, pp. 26–27.
Describes the geology, ore deposits, and workings of the Planet mine.

1907 Smith, F. C., The cyanidation of raw pyritic concentrates: Trans. Am. Inst. Min. Eng., vol. 37 (for 1906), 1907, pp. 570–575.
Describes the methods of the Socorro gold company, near Harrisburg.
1907. Hately, George, Copper mining on the Colorado River: Min. World, vol. 26, p. 809.
Gives a few notes on the geology, ores, and locations of properties in Arizona and California in the vicinity of the town of Parker, Ariz.
1908. Lee, W. T., Geologic reconnaissance of a part of western Arizona: Bull. U. S. Geol. Survey No. 352, 1908.
Notes on the geology of a part of the region here discussed.
1909. Blake, W. P., A report to Hon. J. H. Kibbey, Governor of Arizona.
Brief description of several minerals from localities within this region.
1910. Stevens, H. J., The copper handbook for 1909.
Various descriptions of copper properties located within the area examined.
1910. Higgins, Edwin, Copper deposits of northern Yuma County, Ariz.: Min. World, vol. 33, pp. 855, 903.
Describes several copper deposits within the area.

Besides these articles there are many notes and references to the district contained in the Engineering and Mining Journal, the Mining and Scientific Press, the Mining World, the Arizona Mining Journal, and other journals, a complete list of which it is impracticable to give, for the articles usually appeared as "special correspondence" or "mining news," the author's name not being given.

HISTORY.

The earliest settlers and prospectors in the region seemed to be on friendly terms with the natives. Later, for various causes, the white man was looked upon as an intruder and had to defend himself constantly against the attacks of the Indians. Hence the early settlement of this part of the region was rather slow, and only a few properties now active were opened in the early days.

Placer gold in paying quantities was discovered [a] in the neighborhood of La Paz as early as 1862, and within a year 2,000 men were searching for the precious metal in this vicinity. From the Planet mine, discovered in 1863, ore was shipped as early as 1868, or perhaps earlier. Ore was smelted and bullion produced in the early eighties, and the slag dump resulting from these operations is said to assay 5 per cent copper. In 1874 the hostile Apaches were placed on Indian reserves and the settlers and prospectors were thus able to carry on their explorations more safely.

The McCracken property, in southern Mohave County, discovered August 17, 1874, by McCracken and Owens,[b] had its best days in the seventies and is reported to have shipped a great deal of ore, The Bonanza, at Harquahala, a short distance from Harrisburg. was located in 1888 and has been the largest producer in this region.

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[a] Hamilton, Patrick, Resources of Arizona, 1884.

[b] Hodge, H. C., Arizona as it is, 1877, p. 70.

The old Los Angeles trail ran right through this area from Ehrenberg to Wickenburg. The Southern Pacific Railroad, completed in 1879, and the Atlantic and Pacific, completed in 1882, no doubt helped to develop the central western Arizona region. However, the former railroad is a little too far south and the latter too far north to assist very materially a country in whose growth transportation is the dominant factor. With the completion of the Arizona and California Railroad from Wickenburg to Parker in 1907 an impetus was given to mining activity throughout the district. Many old claims were relocated and new ones were staked out. The Clara Consolidated Mining Company has built a railroad from Bouse to Swansea, called the Arizona and Swansea Railroad. Other proposed roads have been surveyed and may be completed in the future.

The towns along the Arizona and California Railroad have all been recently built and have attracted some of the inhabitants from the smaller places more remote from the railroad. At the present time (January, 1910) Parker, though containing only a few hundred persons, is probably the largest town in the area. The population of such places is constantly changing, however, so that it is not possible to give authentic data concerning the population of the area or of the settlements within it.

CLIMATE.

Unlike the greater part of Arizona, which is over 3,000 feet in elevation, the portion covered in this reconnaissance and that south of it is practically all under 2,000 feet. This low elevation, combined with the southern latitude and the desert conditions which prevail throughout the region, tends to produce intense heat in summer, which makes life, to one not acclimated, almost unbearable. During the months between November and May, however, the climate in central-western Arizona is most enjoyable because of the continuous mild, even temperature with almost perpetual sunshine and the lack of the intense desert glare which is so trying during the summer months.

The United States Weather Bureau at Phoenix publishes some very interesting statistics regarding average monthly precipitation, snowfall, temperature, frost, humidity, and wind direction for several of the stations included in this reconnaissance. The maximum temperature recorded at Parker, Ariz., near the western border of the area covered by this reconnaissance, occurred in July, when the thermometer reached 127° Fahrenheit. The minimum occurred in January, when the mercury dropped to 16°. The mean annual temperature for a period of 12 years is 70.9° Fahrenheit. At Signal station located at an elevation of 1,652 feet in the northeastern part of the area examined, the maximum temperature recorded is 121°, the minimum is 10°, and the mean 67.4°. There is little or no snowfall in the area, but occasionally a slight covering is noted on top of the peaks of the Harquahala and the Harcuvar Mountains. The prevailing wind direction at both Parker and Congress is southwest. The mean annual precipitation recorded at Parker during a period of 8 years is 4.27 inches, and records at Signal station during a period of 15 years show a mean annual precipitation of 7.37 inches.

VEGETATION.

Cacti of many different varieties form the most abundant vegetation in the area. These can not be utilized to any great extent in an economic way and are interesting mainly because of their prodigious growth. Cholla (*Opuntia fulgida*) of several different varieties, prickly pear (any cactus of the genus *Opuntia*), nigger head (*Echinocactus*), greasewood (*Sarcobatus maximiliana*), and palo verde (*Cercidium torreyanum*) abound in the low country; and ocotillo (*Fouquiera splendens*), yucca, and sahuaro (*Cereus giganteus*) are very common in the hills and mountains. Mesquite and ironwood are fairly abundant on some of the mountain slopes and are used principally for fuel. A certain variety of oak is also found, but is not very common.

Along Williams and Colorado rivers, the only two running streams in the area, there is an abundant growth of cottonwood and palo verde—a most acceptable sight to the traveler who has crossed miles and miles of desert waste. Most of the washes in the district contain palo verde and greasewood, and the latter is common throughout the desert. Sagebrush, gietta, and other coarse grasses are plentiful in the valleys and low country. Mesquite beans, a product of the mesquite tree, contain a large percentage of grape sugar, and are supposed by the natives to afford a very nutritious food.

TIMBER.

As ironwood is unfit for use in the mines and as no other large trees grow here in sufficient number to afford timber, it becomes necessary to ship in all the timber from outside districts. Oregon pine is shipped down the coast in boats and freighted by rail to points in central-western Arizona at a total cost of $24 to $28 a thousand feet delivered at any Arizona and California Railroad station. Some timber is also obtained from nothern Arizona at a cost about equal to that of Oregon pine. The freight rate (January, 1910) on lumber from southern California to Arizona and California Railroad stations is $8 a ton in carload lots. The freight rate to these stations from Flagstaff and Williams is $6.40 a ton, and the freight on stulls and lagging from these same points is $5 a ton.

MINING AND METALLURGY.

CONDITIONS AND COST OF MINING.

General conditions in the region.—In central-western Arizona mining is not carried on under the most favorable conditions. Wood, timber, and water are scarce, and most of the properties are far from the railroad, so that a long haul is necessary in order to ship out the ores and bring in supplies. Fuel, whether gasoline, crude oil, distillate, or coal, must be hauled from the railroad to the mines, and at some mines water must be pumped from distant places or hauled by wagons. Wood also must be hauled, some of it for long distances. All these items increase the expense of mining, and as the region is undeveloped, few data are available to show the cost of these operations.

Freight costs.—The property of the Cunningham Pass Copper Mining Company is about 11 miles by wagon road from Wenden, the nearest railroad station. The ascent from the railroad to the property is gradual, the road crossing only one small divide. Freight to Wenden is $4 a ton, the back freight being $3. The cost of hauling freight to the Bonanza mine from Salome, a distance of 10 or 11 miles by wagon road, was given by the management as $4 a ton on small shipments and $3.50 a ton on large consignments. Hauling freight 28 miles to the Planet property is reported to have cost from $10 to $18 a ton, and the superintendent of the San Marcos reported a cost of $4 a ton for freight haul between their property and Wenden, a distance of only 5 miles.

The railroad freight rates from all points on the Arizona and California Railroad to certain smelters are uniform for ore of the same grade. For example, the rate (March, 1909) to the Arizona Smelting Company at Humboldt on ores not exceeding $15 a ton was $2; not exceeding $25, $2.50; not exceeding $35, $3; not exceeding $50, $3.50; not exceeding $100, $5, and not exceeding $300, $6.50. Probably the freight charge on most of the ore shipped from the district would be less than $5 a ton.

The freight rate from all Arizona and California Railroad points to El Paso, Tex. (March, 1909), on ores not exceeding $35 is $6; to Sasco, Ariz., on ore not exceeding $30, $4.95; to Denver, Colo., on ore not exceeding $50, $11; and to San Francisco, Cal., on same class of ore, $10.50.

Most of the ore from the Arizona and California district has been shipped to Humboldt, Ariz., but since the closing down of the smelter at that place[a] the ore has been shipped to smelters at Sasco, Ariz.,[b] and El Paso, Tex., and to other points in the Southwest.

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[a] This smelter is now (February, 1911) in operation.

[b] This smelter is now (February, 1911) closed.

The freight rate on coal from Gallup, N. Mex., whence most of the coal used in the region is shipped, is $4.15 a ton in carload lots to any point on the Arizona and California Railroad. The freight on distillate from Los Angeles is $17 a ton, and the freight on crude oil from Bakersfield, Cal., is $6 a ton.

Smelter charges.—The treatment charges of the smelters naturally vary considerably, according to the class of ore to be smelted. On copper ore from the Cunningham Pass property, which averaged about 12 per cent copper, 0.7 ounce gold, 12 per cent iron, and 54 per cent insoluble matter, the smelting charges of both the Humboldt and the El Paso smelters averaged approximately $8 a ton. This high rate is due to the large percentage of silica, a penalty of 10 cents per unit excess silica over iron being charged by the smelters.

On gold ore shipped from the Pittsburg Harqua Hala property (San Marcos) to the Humboldt smelter the treatment charges were $10 a ton for ore of the following analysis: Gold, 1.56 ounces; silver, 0.34 ounce; insoluble, 88 per cent; iron, 5.4 per cent. The dominant factor in smelting charges for most of the ores in this region is naturally their content of iron and silica. The silica content of many ores is high and increases the smelter charges proportionally.

Cost of mining.—The actual cost of mining the ore differs so much according to location of properties, scale of operations, and other factors that it is hardly possible to give figures that are even suggestive. The lowest prices given were $2.50 and the highest $9 a ton. The cost of mining at some properties in this district no doubt exceeds $9 a ton. Under present conditions, therefore, in order to determine the average complete cost of production (including shipment to smelters) it is well to figure on railroad freight charges of $4; hauling charges, $4 to $20; treatment charges, $6 to $10; mining costs, $2.50 to $9—an average minimum total of $16.50 and an average maximum total of $43 per ton of ore mined and shipped. These figures, of course, apply only to ore which is not concentrated and which is shipped directly to the smelters.

Smelters.—Most of the ores from this district are shipped to custom smelters outside of the area, but there are several smelters of very small capacity and other reduction works of various kinds in the region. At present (January, 1910) there is in progress of erection a 700-ton smelter at Swansea, Ariz., where the Clara Consolidated properties are located. This smelter will probably do custom work, as it is located in the center of large deposits of hematite in limestone, which form the main part of the Signal ore deposits, and which will be an excellent flux for siliceous ores shipped in from the outside. On the completion of the Arizona and Swansea Railroad this smelter will be as easy of access to the properties in the district as are the custom smelters outside of the area and will be nearer.

Two small copper smelters (neither of them active at present) are located at the Planet and the Valensuella properties, and a quicksilver smelter is located at the Cinnabar workings in the southwestern part of the area. Various adobe furnaces have been operated in this region in the past with some success, but this method of smelting is now obsolete.

Mills.—Mills of various types and sizes have been constructed in the area. The Socorro mill and the process of ore separation there employed have already been fully described.[a]

Probably the largest mill in the area is that at the Bonanza (Harqua Hala) mine. This mill has 40 stamps, and when it is running at full capacity the company can mine and mill ore for $2.50 a ton. The plan of the mill is very simple, the ore passing over grizzlies into the rock crushers, from them into feeders, and thence into the batteries. Quicksilver is used in the mortars and on the plates. The water used in the mill comes from the mine, which furnishes about 3,000 gallons a day. This water, used over and over, will suffice for 20 stamps. Other water is piped from the pumping station at Harrisburg, about 5 miles distant.

Numerous small stamp mills have been erected in various parts of the area, nearly every mining district having one or more within its boundaries. These have been more or less successful, and one or two still remain in good repair; most of them, however, have become worthless, mainly because of partial dismantlement and lack of use.

Labor.—Labor conditions are apparently adjusted to the progress of the mining activity of the country, there being plenty of miners wherever there is ample work for them. Wages are about the same as those paid in other mining districts of the Western States.

METHODS OF MINING.

Most of the mining in the area is carried on by inclined shafts, but there are a few vertical shafts, some crosscut adits, and drifts on the veins. The presence of so many inclined shafts is probably due to the fact that most of the veins have a fairly gentle dip (30°–60°), and the easiest and safest way of exploration seems to be to follow the vein. Fairbanks-Morse hoists are used almost universally, the average size being 9 to 15 horsepower. Distillate is used for fuel and costs approximately 15 cents a gallon in carload lots delivered at any Arizona and California Railroad point. In smaller lots, by the tank, it costs about 17½ cents a gallon. Some of the larger properties use steam hoists, generating steam by crude oil that is shipped from Bakersfield, Cal. The oil costs $1.75 a barrel (40 gallons) at Arizona and California Railroad points. One wire-rope tramway has been used, connecting the Golden Eagle property with the Bonanza mill, about a mile distant. The country is not developed enough to require a lengthy description of the methods of mining, all the mines being more or less in the prospecting stage.

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[a] Smith, F C., The cyanidation of raw pyritic concentrates: Trans. Am. Inst. Min. Eng., vol. 37, 1907.

PROPERTIES EXAMINED.

The properties in the region which are supposed to be, in some particulars at least, the more prominent are listed in the following table. The table also includes, however, some obscure prospects that were examined because of their proximity to well-known deposits which were studied with more or less detail. For lack of time, some locally well-known properties could not be examined.

List of properties examined.

No.	Name of operator, owner, locality, or mining company.	Property ordinarily called the—	Mining district.[a]	Active (x) or inactive (v) at time of examination.
1	Planet Copper Mining Co	Planet mine	1	v
2	Mineral Hill	Norma	1	v
		Mohave Chief	1	v
		Copper King	1	v
3	Clara Consolidated Gold and Copper Mining Co.	Clara	1	x
		Moro	1	x
		Signal	1	x
4	Quartz King Gold Mining Co	Quartz King	1	x
5	William Mack	Billy Mack's mine	1	v
6	Mr. Watson	Carnation group	1	v
7	Mr. Osbourne	W. & O	1	v
8	Mr. Osbourne et al	Dome City	1	v
		Mineral Zone	1	v
		Mail Pouch	1	v
		Pride	1	v
9	Corona Copper Co	Chicago	1	x
		Mammoth	1	v
		Also others	1	v
10	Valensuella Copper Co	Valensuella	2	x
11	Julia Travis	Mariquita	3	v
12	Colonial Mining Co	Cinnabar	3	v
13	French-American Mining Co	French-American	3	v
14	New York-Plomosa Gold Mining Co.	New York-Plomosa	3	v
15	Guadalupe	Guadalupe (Moreno)	3	v
16	Ibex Mountain	Lead Camp	3	v
17	Mr. Mudersbach	Mudersbach Copper Camp	3	v
18	Forepaw	Iron Mine	3	v
19	Little Butte Consolidated Mines Co.	Little Butte	3	x
20	Yuma Copper Co	Yuma	4	v
21	Yellow Bird	Yellow Bird	4	v
22	Alvin Griffith et al	Arizona Northern	4	v
23	Mr. Winchester	Desert Prospect	4	v
24	Calcite Mining Co	Calcite	4	x
25	Tank Pass Consolidated Mining Co.	Cobralla	4	v
26	Bonanza-Golden Eagle Mining Co	Bonanza	4	x
27	Hercules Gold Mining Co	Hercules	4	v
28	Socorro Gold Mining Co	Socorro	4	v
29	Pittsburg Harqua Hala Gold Mining Co.	San Marcos	4	v
30	Cunningham Pass Copper Mining Co.	Critic	4	x
		Boone	4	v
31	Mr. Bullard	Bullard's	4	v
32	McCracken Mountain	McCracken	Owens	v
33	Viata Mining Co	Bennett's	Monumental, Cal.	v
34	Copper Basin	Copper Basin	do	v
35	Bowman & Thompson	Bowman's	do	x

[a] For map of mining districts, see figure 4 (p. 45).

OTHER PROPERTIES.

On a recent map published by E. A. Haggott many other properties are also noted, but the author is unaware of the development or the exact location of most of them. Few of them were being actively developed at the time the field work for this report was done. Their names and the regions in which they are located are given below.

In the Harquahala Range—the Boneroff, Sunset, Mountain Chief, Yuma, Del Monte, Big Four, Shawnee, Cholla, Evergreen, Shamrock, Martin, Genung, Geer's, Sayer, Golden, Dushay, and Armstrong properties.

In the Harcuvar Range—the Ford, Ewar, Lind-Griffin, Dolan's, Beekman, Hughes, Quinn & Scales, McDonald, Lester, Torres, Bell Crown, Akers, Oro Cobre, Robinson's, Lessens, Harcuvar Copper Company, Josephi's, Agard's, C. & O., Auditorium, and Burson & Wallace properties.

In the Williams Mountains south of Williams River—the Red Bird, Midnight, Montana-Arizona, Blanco, Wentworth, Revenue, Blanchard's, Continental, Juanita, Gier, Black Diamond, White Eagle, Mavis, Richmond, Gray Eagle, Belcher, and Cyclone properties.

In the Williams Mountains north of Williams River—the DeWitt, Rawhide, New Clara, Bryan, McCuen, Casteneta Copper Company, McWright, and Profetto properties.

In the Plomosa Mountains—the Moore, Success, King Verde, River, Smith, Zero, Vulcan, Edna, Quinn & Gaynor, Ibex, Old Maid, Manipulator, and Bellows properties.

In the Dome Rock Mountains—the Bowyer, Harris, Virgin Queen, Copper Bottom, and Ida May properties, the latter, however, being located in the isolated hills south of Parker some 10 or 15 miles, which hills may be taken as a northern remnant of the Dome Rock Mountains.

In the Whipple Mountains (California)—the Dunn, Hinaman, Martin, Black Metal, Manning, Dunkirk, Dickson, Copper Chief, Lily, St. Clair, Lucky Boy, Raney, Friday 13th, Mount Whipple, Honn, Brazle, Wareham, Garrett, Young, Klondyke, White, Dunbar, Wilson, Confidence, Grand Central, Hawn, Baltimore, Copper, Roths, Blue Bird, Cat Claw, National, American Eagle, A. C. Group, D. & W., Atkinson, Nicolite, Copper Basin,[a] Bowman's,[a] and Viati properties.[a]

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[a] Described in the text of this report.

TOPOGRAPHY.

RELIEF.

GENERAL FEATURES.

The country investigated in this reconnaissance shows typical desert topography. The area covered by the mountain ranges is exceedingly small as compared with that of the valleys. Most of these ranges rise abruptly out of the desert, and the intervening valleys, which slope with decreasing declivity down to the washes leading to Colorado River, are filled with detrital material resulting from the erosion of the mountains. In places the slopes of the ranges are almost covered with this erosional débris, so that the most impressive feature seen by an observer looking toward the upper end of a valley is the broad gentle slope to the deserts that lie between the mountain ranges. In the northern part of the area lava flows have tended to make the topography somewhat rolling. The foothills of the Williams Mountains are composed of such lava flows, and the Whipple and the Plomosa Mountains owe part of their prominence to lava flows that cap the older eroded rocks and in places surround their bases. No deeply dissected stream valleys are present in the area except in the washes near Williams and Colorado rivers, where fairly steep, though short, precipitous canyons have been formed. The axes of the mountain ranges extend in two separate lines, one northeast and southwest, the other north and south. It is possible that this latter direction may have resulted from erosion in the original stream course of Colorado River, which possibly at one time flowed down the valley in which Quartzsite is located.

The lowest elevations in the area occur along the present stream bed of Colorado River, which is below 500 feet. The highest peak, Harquahala, attains an elevation of over 5,500 feet, the valley just north having a general elevation of 2,200 feet. The average difference in height between the mountain tops and the valleys, however, is about 1,500 or 2,000 feet.

In the main, the mountains are carved from old crystalline and metamorphic rocks, and the ridges and slopes are therefore fairly regular and lack the abrupt cliffs and terraces characteristic of ranges in which the sedimentary rocks participate largely in the structure. In detail, however, the landscape bears the imprint of desert erosion, of which small but steep scarps, jagged outcrops, and sharply cut ravines are typical.

Because of the almost total lack of vegetation in the region little or no soil covers the mountains, the result being that their contours and natural colors stand out with very marked prominence.

MOUNTAIN RANGES.

Principal features.—This area includes six distinct mountain ranges, of which the Harquahala and the Harcuvar are the most prominent and well defined. The others are the Plomosa, the Williams, the Whipple, and the Dome Rock mountains. The hills commonly called Granite Wash Mountains are really a continuation of the Harcuvar Range, and to set them apart in a separate division is not only unnecessary but incorrect and misleading.

Harquahala Range.—The Harquahala Range is separated from the Harcuvar Mountains by Granite Wash Pass. The southwest end of the Harquahala Mountains is composed of low but prominent peaks, which rise several hundred feet above the surrounding flat desert. Centennial Wash practically cuts the Harquahala Mountains in two. Northeast of Harrisburg the range is less dissected by erosion, and Harquahala Mountain caps the range, at an elevation of 5,669 feet. This range is distinguished from the others by the compact form of the main mountain mass. In the rest of the area there are many prominent peaks, but few, if any, individual mountains which are nearly as large as Harquahala. In fact, the character and conspicuousness of the range seems to depend largely on this one mountain.

Harcuvar Range.—Of all the ranges in the area, the Harcuvar is probably the most continuous and uniform in general contour. Many prominent peaks project a few hundred feet above the average elevation of the range, and when observed from a great distance these seem, with the exception of Harcuvar Peak, like very small knobs projecting from a high plateau. The general trend of the mountains is northeast-southwest, the southwestern extremity turning abruptly to the south, where it practically joins the Harquahala Range. Harcuvar Peak is the most prominent in this range and is second only to Harquahala Mountain in being the most conspicuous landmark in the area.

Other mountain ranges.—North and south of Williams River the country for several miles is built up by low foothills which gradually rise to the base of a few prominent peaks, among which Planet is by far the most noteworthy, and these constitute the Williams Mountains. They are so decidedly different from the other ranges in the area that the presence of foothills is worthy of remark.

Of the remaining Arizona mountain ranges to be discussed, the Plomosa Mountains[a] (distinguished by the Black Mesa) are probably more prominent and certainly cover a greater area than the Dome Rock Mountains. Both ranges are in the southwestern part of the area and are separated from each other and from the remaining mountain groups by broad valleys. The trend of the mountains is north-south in both instances.

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[a] These are called the "Palomas" by Lee; Bull. U. S. Geol. Survey No. 352, 1908.

The Whipple Mountains, located in California and culminating in the well-known landmark, Monument Peak, show characteristic topographic forms which may be accounted for by the geology of the range. There is a difference of over 3,000 feet between the top of the highest mountain in the Whipple Range and the Colorado Valley, which is some 10 miles distant.

DRAINAGE.

Colorado River and its tributaries drain the whole area. Williams River, tributary to the Colorado, has running water throughout the year in its lower course. Part of the year Big Sandy and the Santa Maria have a regular flow, and during this period the Williams has running water continuously. In the rainy season the various washes frequently have a large flow of water, but this is only of temporary duration, seldom lasting over two days and frequently only several hours. Some peculiarities in drainage may be seen by referring to the general map (Pl. I) which accompanies this paper. South of Salome there is a very low divide, which forms a prominent watershed. Also, on the road from the Guadalupe to Vicksburg a divide is passed, southeast of which all water is drained in that direction, while to the northwest the drainage is in the opposite direction.

Bouse Wash probably drains more country than any other wash in the area.

GROUND-WATER LEVEL.

In this part of Arizona the ground-water level fluctuates with the seasons and is different at different localities, and no definite distance below the surface can be given as the present water-table level. In general this conforms to the topography of the mountain ranges, although there are many exceptions, and erratic underground channels are found in parts of the area. Near Harrisburg, in Centennial Wash, there is an extensive flow a few feet below the surface, and a company is now building a dam across the channel of this stream, hoping thereby to conserve the water for use in the valley. In the Bonanza, Cunningham Pass, and Little Butte properties the water level is about 170, 320, and 200 feet, respectively, below the collar of the shaft.

GEOLOGY.

GENERAL GEOLOGIC FEATURES.

The rocks of the region as represented on the geologic map (Pl. I) have been divided into pre-Cambrian, Mesozoic (?), Tertiary, and Quaternary.

Pre-Cambrian.—Pre-Cambrian rocks compose practically all the mountain ranges except those near the mouth of Williams River and some scattered mountains in other parts of the area which are capped by lava flows. Nearly all of the ore deposits are found in the pre-Cambrian rocks, so that these will necessarily receive more attention than the others.

Granites, gneisses, schists, quartzites, limestones, dolomites, and argillites constitute the pre-Cambrian rocks, all of which are at many places cut by intrusive rocks of different kinds and ages. Diabase, pegmatite, and aplite are the most common dike rocks in the pre-Cambrian, but other types also are present.

Mesozoic (?).—The age of the large and massive granite intrusion in the Harcuvar Range is not known. Certainly it is younger than the pre-Cambrian strata through which it cuts. Because of the fact that so many granite intrusions have taken place in the Pacific States in Mesozoic time, this one is assigned temporarily to that era, no fossils having been found in the area either to substantiate or disprove the correctness of the assignment.

Tertiary.—The lava flows, with the exception of some of the basalts which are interbedded in and rest on top of Temple Bar conglomerate,[a] have been assigned to the Tertiary system. Several of the ranges are capped by volcanic rocks, and many prominent peaks in the area are composed entirely of igneous flows.

Quaternary.—The broad valleys between mountain ranges, the river banks, and the thick gravels which occur north of Williams River cover by far the largest part of the map. All of these, including most of the basalts, belong in the Quaternary system.

PRE-CAMBRIAN ROCKS.

GRANITE-GNEISS-SCHIST COMPLEX.

The oldest rocks in the area are probably of Archean age. They are granitic; many are gneissic and some are decidedly schistose in structure. The major part of the Harcuvar Mountains north of Harcuvar Peak is composed of this type of rock, as is the Harquahala Range north of Centennial Wash. Material belonging to this complex makes up much of the Williams Range and also forms the basal portion of the Whipple Mountains in California, and no doubt underlies and forms part of the Dome Rock and the Plomosa mountains. In some places, as at Socorro and Little Butte, the granite is of normal structure; at the Signal, the Cunningham Pass, and the Planet workings the basal rock is decidedly gneissic. At the San Marcos and elsewhere the granite is in part normal, but often changes very abruptly to gneiss, there seeming to be no regularity in the change from normal granite to gneiss and schist.

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[a] Lee, W. T., Bull. U. S. Geol. Survey No. 352, 1908, p. 18.

These rocks occur in many colors, white, pink, and gray predominating, the color in many places depending on the presence and alignment of the ferromagnesian minerals and the degree of alteration of any or all of the constituents of the rock. Some of the schists have a blackish cast. The Harcuvar Range as a whole looks decidedly gray, the tone probably resulting from the white feldspar and black mica constituents of the rocks. The gneiss just south of the Signal and north of the Planet is of a pinkish cast.

Basic rocks of dioritic composition were intruded into the granites before the metamorphism of the area, and have been metamorphosed along with the rest of the series.

Pegmatite and aplite dikes are common throughout the granite gneiss schist area. Some of these intrusions are of large proportions, being several hundred feet wide and perhaps several thousand feet long. Generally the pegmatite dikes are of smaller dimensions.

Thin sections of granitic gneiss examined under the microscope show holocrystalline structure and a composition of microcline and orthoclase feldspar, with perhaps a little albite, associated with considerable quartz and a noticeable amount of biotite. Some augite is present in the rocks and a very small amount of calcite. Each mineral is remarkably fresh, even the feldspars showing hardly any signs of sericitization.

The basic dioritic gneiss has a structure similar to that of the granitic gneiss and is composed almost entirely of hornblende with andesine or labradorite feldspar with here and there a few crystals of quartz.

The schists have in general the same composition as the gneisses, the difference between the rocks being merely textural. Most of the schists in the area, however, not belonging to this granite gneiss schist complex are of quite different origin, being for the most part recrystallized sediments.

Granitic aplites (fine-grained muscovite granites) are composed of quartz, orthoclase, and muscovite.

Pegmatite represents another phase of granite, being composed of very large crystals of orthoclase, quartz, and mica.

METAMORPHOSED SEDIMENTS AND SEDIMENTARY SCHISTS.

POSITION AND CHARACTER.

Resting on and younger than the granite gneiss complex are metamorphosed sediments, not schistose, and sedimentary schists. Of the former only a thickness of a few hundred feet now remains, while of the latter several thousand feet can still be seen in the area. The first type is composed of quartzites, limestones, and dolomites, and the second of argillites and arenaceous shales, metamorphosed into fine-grained quartz-mica schists, both of which types are believed to be of pre-Cambrian age. To the writer's knowledge neither of the groups can be correlated with any known division in Arizona. Because of their lithologic and structural characters they are not comparable to the Pinal schist of Ransome, the Arizonian of Blake, or the Yavapai schist of Jaggar and Palache. Nor are they considered analogous to the little-altered, nearly horizontal sandstones and shales (Unkar and Chuar groups) of the Algonkian in the Grand Canyon section. The Pinal and Yavapai schists are fine-grained quartz muscovite sedimentary rocks, which are entirely free from limestones and quartzites, the whole being intruded by innumerable granitic rocks of pre-Cambrian age.

In this area these metamorphosed sediments and sedimentary schists contain limestones, dolomites, quartzites, amphibolites, and quartz-mica schists, and in no places noted were they intruded by granitic rocks which appeared to be of pre-Cambrian age. Hence it is impossible at the present writing to correlate the rocks found in this regionally metamorphosed area with any known formation outside.

Sheets of basic rocks have been intruded into and poured out over the various sediments at many different periods, so that the complex has intercalated basic rocks (now amphibolites) which have been metamorphosed along with the rest of the series, the result being a very intimate association of the two.

QUARTZ-MICA SCHIST GROUP.

The rocks which appeared to be the oldest in this complex of metamorphosed sediments and sedimentary schists are the medium-grained to coarse-grained quartz-mica schists in the vicinity of the Valensuella workings. These dip northwest away from the gneissic micaceous granite found south of Tyson Wash, which is probably the oldest rock in the vicinity and is perhaps comparable to the granite gneiss complex of the Harcuvar Range. The schists attain a thickness of several hundred feet, vary in color from gray to black, and seem to be derived from the erosion of a quartz-mica diorite. Under the microscope the thin sections show the presence of much labradorite and nearly an equal amount of orthoclase feldspar, associated with quartz and a noticeable amount of white mica. Pyroxenes in small quantities are present in some of the schists, and chlorite is rather abundant. Rocks of similar composition and texture were noted in many other parts of the area and in general seem to underlie the quartzites, dolomites, limestones, fine-grained quartz-mica schists, and argillites.

Near the Calcite workings a section was observed in which the basal rock was a coarse-grained quartz-mica schist similar to that in the vicinity of the Valensuella. Over this occurs a few feet of very much altered, fine-grained quartz-mica schist, which is in turn overlain by a few feet of quartzite capped by several feet of quartz-mica schist with another thin layer of quartzite on top, the whole section being perhaps 100 feet thick. The canyon between the Calcite property and the Desert prospect, known as Desert Canyon, is cut in a series composed mainly of arenaceous shales and argillites, the total thickness of which is several thousand feet.

QUARTZITE-DOLOMITE-LIMESTONE GROUP.

In the vicinity of the Bonanza (Harqua Hala) mine the series resembles greatly that found near the Socorro workings. South of the Bonanza mine a thin stratum of quartzite overlays coarse-grained crystalline rocks of granitic composition and is in turn capped by a few feet of dolomite and by 200 or 300 feet of schists, limestone, and shale. On top of the ridge just south of the Bonanza mine a massive layer of gray limestone is found, which is 50 to 100 feet in thickness. This limestone appears to be younger than that seen in the vicinity of Planet and the Clara Consolidated and elsewhere, but it is nevertheless believed by the author to be of pre-Cambrian age. This is similar in many respects to a limestone noted near the Mudersbach copper camp.

In the vicinity of the Socorro mine a similar series is observed, where 100 to 200 feet of quartzite rest upon a granitic base, and on top of the quartzite occurs several hundred feet of yellowish crystalline limestone, near the upper portion of which intercalated argillites and fine-grained quartz-mica schists occur. It is possible that these argillites are comparable in age to those found in the vicinity of the Desert prospect, where medium to fine grained quartz-mica schists also form a part of the series, but the whole series has a somewhat less altered aspect. No fossils could be discovered.

The quartzites vary in color from white to pinkish gray, and in general seem to be rather pure. They are in most places very compact and highly silicified, most of those seen being fine-grained, although coarse-grained quartzites are present in the area, some having been noted at the Bonanza mine. In no place where quartzites were noted did the thickness exceed 200 feet, and generally it was much less.

The only dolomite definitely recognized as such was found near the Bonanza mine, where it is only of nominal thickness. This is of a dark-gray color and contains many vugs and transverse fissures filled with iron-stained calcite. The rock is exceedingly fine grained and has a glistening surface. A partial analysis showed the presence of 20.59 per cent magnesia.

Limestones of various sorts were found in beds ranging in thickness from a few inches to several hundred feet. Some are pure white coarsely crystalline marble, and the majority are fine to medium grained yellow, brown or dark-brown crystalline limestones. Analyses of three typical specimens of the fine-grained variety gave the following results:

Analyses of limestones from northern Yuma County, Ariz.

[Chase Palmer, analyst, U. S. Geol. Survey.]

Locality.	CaO.	MgO.	Loss on ignition.
Battleship Mountain	52.57	0.23	41.75
Planet, dump of vertical shaft	44.63	2.11	36.98
Planet, limestone used as flux in smelter	34.15	2.99	30.00

ARGILLITES AND ARENACEOUS SHALE GROUP.

The remaining group of metamorphosed sediments, composed of argillites and arenaceous shales, the latter having been metamorphosed into fine-grained quartz-mica schists, is of wide distribution.

The argillites are found in a typical exposure in the vicinity of the Desert prospect, 2 miles north of Vicksburg, where the formation attains a thickness of several thousand feet. The series alternates with arenaceous strata and calcareous beds and a great number of amphibolitic layers of varying thickness. Clay shales of the same general type were also observed at Mineral Hill and intercalated in the limestones near the Socorro workings. The rocks in the vicinity of Cinnabar appear to be mainly of the fine-grained quartz-mica schist type and are prominent in the Dome Rock Mountains. The argillites are greenish to dark gray or almost black in color, resembling in many respects roofing slates. They seem to be composed largely of carbonaceous matter, with which is associated approximately equal amounts of feldspar and quartz, the former having largely changed to white mica. Chlorite is present in some of the argillites and in places to such an extent that the rock has a decided greenish tone.

The arenaceous shales which have been metamorphosed into fine-grained quartz-mica schists have every conceivable color, ranging from silvery white to gray, brown, yellow, red, and a color which approaches black. The principal constituents of the rock are, as its name implies, quartz and mica, the latter usually being in the form of sericite, presumably resulting from the decomposition of feldspars. The colors are due in general to the kind of mica and the amount of epidote and chlorite present, and in part to the degree of oxidation of the contained iron. Some specimens of the rocks feel greasy and are readily scratched with a knife blade, showing characteristics due to the presence of a large percentage of mica.

INTRUSIVE ROCKS.

Basic rocks.—Throughout the area diabase and the derivatives of other basic rocks are almost universally present in large exposures of pre-Cambrian rocks. In places they appear to have been intruded prior to the development of schistose structure in the region; in others they occur as sills occupying bedding planes between strata; and here and there the diabase cuts across all formations, this evidently being the youngest phase of these intrusive rocks. Part of the basic rocks are schistose, some are massive, and most of them have undergone metamorphism so great that they now form amphibolitic rock.

Where these rocks have intruded formations other than limestone they seem to have either cut the formation entirely or else to have formed sills or sheets between the various strata. With the limestone, however, conditions are locally quite different, and frequently great thicknesses of the material can be seen in which the metamorphic amphibolite plays an important part. In the vicinity of Battleship Mountain, Limestone Mountain, Planet, and elsewhere, the limestone seems to have been partly absorbed by and literally saturated with the basic rock, so that the result is like that produced by immersing a fractured brick in hot slag, or, better, like bricks after long service in mercury condensers. Perhaps the basic rock was introduced under the weight of former overlying sediments and filled all of the open spaces, besides replacing parts of the limestone.

In other localities, as at Billy Mack's, there seem to have been alternate periods of deposition of sediments and of basic flows, one on top of another, the whole being later metamorphosed and tilted to its present position.

Many of the dark-colored intrusives in the area resemble megascopically the diabases and other related rocks. As microscopic study has shown these to be connected with the Mesozoic (?) granite intrusion, they will be discussed in that connection.

The diabases have a general greenish tone and are phanerocrystalline, having a medium to fine grained texture. Thin sections of the younger phase of the diabases examined under the microscope show ophitic structure, the chief constituents being augite and labradorite, with which is associated a considerable amount of epidote and calcite.

The amphibolites found in this area were probably formed through the alteration of basic rocks like diabase, diorite, or gabbro. These amphibolite masses are of various shades of green and are usually rather soft, being composed largely of some amphibole mineral, associated with a little quartz and much chlorite and talc.

Dikes.—True pegmatites seem to be conspicuously absent in the metamorphosed sedimentary complex, but it is the writer's belief that much of the so-called vein and "bull" quartz found throughout the series is of pegmatitic origin and is probably connected with later intrusions in the area, which will be discussed under post-Cambrian rocks.

Aplite of texture different from that observed in the granite gneiss schist complex occurs at many places in these metamorphosed sediments. This is no doubt likewise connected with the intrusion of granite in the southwestern part of the Harcuvar and the Harquahala ranges and will be discussed under Mesozoic rocks.

Other intrusives.—As the occurrence of other intrusives has only local significance, they will be discussed under the detailed description of mineral deposits.

POST-CAMBRIAN ROCKS.

MESOZOIC (?) INTRUSIVE ROCKS.

GRANITE.

Of the various post-Cambrian intrusives found within the area, the granite occurring in the Harcuvar Range and forming parts of its southwest extremity is probably the most prominent.

Two large masses of this granite were seen, one of which forms Harcuvar Peak and the other forms the range from a little west of Harcuvar Peak to a point just southwest of Salome Peak. Numerous other occurrences of smaller dimensions were noted. The intruding magma may have sent out stringers which outcrop at various distances from the parent mass, and which have no surface connection with the main intrusion. Branching masses of this granite are exposed in Granite Wash Pass and also near the Calcite workings. In places the intruding magma has suffered more severe metamorphism than the surrounding rock. On the other hand, some of the sedimentary schists have practically absorbed the granite and its accompanying solutions. Apparently the degree of absorption and alteration of the granitic magma depended upon the composition of the intruded rocks. Limestone, for example, was profoundly altered, but the schists seem to have been only slightly changed. Where later granitic dikes cut the granite, large contact minerals were developed, such as hornblende crystals more than an inch in length and biotite crystals more than one-half inch in diameter. The rock shows to the unaided eye large feldspar, quartz, and biotite crystals, and is apparently epidotized to some extent. Examination of thin sections reveals the presence of microcline and orthoclase feldspars with a little albite, much quartz, biotite, and hornblende, and a very small amount of augite. Epidote is fairly conspicuous.

In the vicinity of Quartzsite a small hill 1 mile due south of the town is composed entirely of a medium-grained, greenish-colored augite andesite porphyry, and another mountain, 2 miles southwest of Quartzsite, is composed of a medium-grained aplite, both of which rocks are probably late intrusives and are no doubt present in many places in the area. Granitic intrusives were noted in the vicinity of the Mariquita prospect, and quartz monzonite porphyry was seen at the Mudersbach copper camp.

INTRUSIVE DIKES CONNECTED WITH THE GRANITE.

Aplite.—Several types of intrusive dikes which commonly accompany granitic intrusion were observed. Of these the most common have aplitic composition, and are of both fine and coarse-grained texture with large exposed surface dimensions, some of them being over a mile in length. These aplites differ from those mentioned under pre-Cambrian dikes in that they are not so jointed and are in general fine grained and massive. In the immediate vicinity of the granite area aplite dikes are extremely numerous, and form a noticeable part of Salome Peak. They also seem to have been more widely distributed through the area than the granite proper, and rocks of similar aplitic composition and texture are found as far away as the Mudersbach copper property. It seems probable that they are connected with the main granitic intrusion.

Vogesite and minette.—Vogesite dikes were observed in several places in the vicinity of Salome and Harcuvar peaks, and minette dikes were noted in the Socorro and Valensuella localities. The former porphyritic rock is characterized by the number of hornblende or augite phenocrysts it contains. These are lath-shaped and stand out prominently on a weathered surface of the rock. Under the microscope thin sections show a predominance of hornblende or augite crystals and some orthoclase feldspar. Apatite is also a noticeable feature of the rocks.

Minette dikes are also porphyritic and are composed of biotite and orthoclase feldspar. Apatite is a conspicuous feature of the rock when viewed in thin section under the microscope, this mineral and the feldspar constituents not being visible upon megascopic examination.

TERTIARY ROCKS.

General character.—On the map accompanying this report (Pl. I) all of the lava flows are represented by one color. A few of the effusives are of Tertiary age; the area occupied by them, however, forms only a small portion of that covered by volcanic flows, the majority of which are believed to be Quaternary basalts.

Volcanic plugs are present in several places in the area, and apparently are more numerous near the lower portion of Williams River than elsewhere. Between Swansea and Planet a plug was noted on the south of the road, some 3½ miles from the former place. Here the limestones appear reddish in color and cellular in structure in the vicinity of the intrusion. Scoria, ash, and chaotic breccia of quartz, rhyolite, and andesite form the principal part of the plug. No flow remains in the vicinity. Elsewhere presumable remnants of plugs were noted at some little distance from the road, but there was no opportunity for a close study of any.

Lava flows.—Volcanic rocks, presumably of Tertiary age, occur a short distance northeast of Bouse, where low hills, extending in the same general direction, are composed of andesitic breccia and lava flows. South of the Little Butte property there is a small remnant of rhyolitic breccia which probably represents a former lava flow. A large part of the Plomosa Mountains is composed of material of igneous origin, the lower portions of which are probably Tertiary andesites. In the vicinity of the main Quartzsite-Vicksburg stage route these mountains are capped by basalts presumably of Quaternary age, the whole series of rocks being about 1,500 feet thick in Black Mesa, 18 miles southwest of Vicksburg. Bullard Peak, about 10 miles a little east of north of Golden, is composed of very basic andesitic material which rests on the pre-Cambrian granite gneiss schist complex—a conglomerate about 100 feet in thickness is overlain by some 100 feet of volcanic ash, on top of which rests a thin layer of andesite, the whole constituting Bullard Peak. Although only 300 feet above the desert at the point of contact with the older gneiss, it is nevertheless a very conspicuous landmark in the area, and probably represents the remnant of a formerly existing flow of wide distribution. The occurrence of copper ore in this formation is a notable feature, and will be more fully discussed under detailed descriptions of ore deposits.

Breccia.—From the general description of Greggs breccia by Lee[a] and from personal conversation with him upon the subject, it seems highly probable to the writer that there is present in this area at least the basal portion of a breccia similar to the so-called Greggs breccia. The actual age of this formation is unknown, although it seems certainly to be late Tertiary.[b] This breccia is composed mainly of coarse fragments of crystalline rock poorly stratified and roughly cemented by calcareous and siliceous solutions.

The Mammoth workings of the Corona Copper Co. are located on the contact of a breccia with the underlying pre-Cambrian granite-gneiss-schist complex. The character of the breccia will be described under detailed description of ore deposits. For the present it is well to keep in mind the fact that if this is Greggs breccia there is evidence here of mineralization during Tertiary times, and this in conjunction with the mineralization at Bullard's (which is also supposed to be in Tertiary rocks) offers substantial proof of at least one definite period of Tertiary mineralization. Just southeast of Castaneta Well there is a small hill rising some 200 feet above the desert, which is composed of a breccia of rhyolite fragments which may be comparable to parts of the Greggs breccia of Lee,[a] and on top of Battleship Mountain a very thin breccia was noted. No doubt there are many other occurrences of the same rock within the area, but these were the only ones seen by the writer. In all occurrences noted the breccia rests on the old pre-Cambrian rocks and is only of nominal thickness, representing perhaps the oldest and basal phase of the formation, which is described by Lee as being 1,400 feet thick in the vicinity of Greggs Ferry.

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[a] Lee, W. T., Geologic reconnaissance of a part of western Arizona: Bull. U. S. Geol. Survey No. 352, 1908, pp. 17, 32.

[b] Idem, p. 60.

QUATERNARY DEPOSITS.

Basalt flows.—In the southwest many of the basalts are commonly called măl′-a-pī—a mispronunciation of the Spanish *mal país* (măl pah-ees′), meaning bad country [b]—a term which is also used to describe the broken character of the country caused by the cubical weathering of the basalts and the subsequent formation of steep cliffs.

According to Lee [c] most of the basalts of central western Arizona belong in the Quaternary system, although he says "Some of the older basalt sheets of the region may also belong to the Tertiary, but this is not definitely known." Schrader [d] gives the age of the olivine basalts found in Mohave County as Quaternary and notes the fact that they cut gravels of this age and occur as a covering to them and to the older rocks.

In the area included in this reconnaissance the basalt flows are numerous and form a large part of some of the mountain ranges. The Williams Mountains, south of the lower part of Williams River, are composed mainly of basalt; volcanic ash or river silt and gravels have filled up the erosional depressions; and the basaltic flows form broad, flat plateaus in places sloping gently down to deserts and elsewhere forming steep sharp cliffs. The section in Lee's bulletin (No. 352, p. 54) is a typical illustration of the mode of occurrence of the basalt flows. North of Williams River, en route to Yucca, about 2 miles south of Castaneta Well, occasional volcanic hills were seen some little distance to the west, and a fairly consistent flow was noted just east of the road. Castle Dome Mountain, observed from a distance of 5 miles, seemed to be made up of volcanic flows, part or all of which may belong to the Quaternary. Ash and basalt were observed on the west side of a small isolated range some 14 miles a little west of south of Parker, where, as in the Williams Mountains, the old drainage valleys and washes have been filled up with ash and erosional débris and the basalt poured out in flat layers. The Plomosa Range south of Ibex Mountain is probably largely composed of volcanic material, of which the upper portions are no doubt Quaternary. On the California side numerous basaltic bowlders were noted on the way to Copper Basin, and it is probable that Quaternary basalts constitute the upper portion of the Whipple Mountains, Monument Peak apparently having been formed from this material.

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[a] Lee, W. T., Geologic reconnaissance of a part of Western Arizona: Bull. U. S. Geol. Survey No. 352, 1908, p. 17.

[b] Ransome, F. L., Prof. Paper U. S. Geol. Survey No. 66, 1909, p. 26.

[c] Lee, W. T., op. cit., pp. 16, 18.

[d] Schrader, F. C., Bull. U. S. Geol. Survey No. 397, 1909, p. 42.

Conglomerate.—North of Williams River, east of the road to Yucca, great masses of reddish conglomerate occupy large areas and occasionally form high mountains. This conglomerate may be comparable to the Temple Bar conglomerate of Lee,[a] which has been described by him as being very similar to the Gila conglomerate of Gilbert,[b] Ransome,[c] and Lindgren[d] from different parts of southern Arizona.

The conglomerate as exposed north of Williams River rests on an older granite base and is composed mainly of round bowlders of granite and schist, which in places attain large dimensions, and is cemented by sandy material. Quartz pebbles are prominent, and the whole hill seemed to be very well consolidated. Potts Mountain, some distance away from the route traveled, appeared to be composed mainly of the same sort of material, although the rocks may be similar to those which form McCracken Mountain. The origin of siliceous cement in the conglomerate can be accounted for when the volcanic plugs in the area are considered. In conjunction with these, hot springs no doubt issued from the ground and locally silicified the gravels and breccia, the remnants of which are now visible in the area.

Gravels and detrital deposits.—Along Colorado River, opposite Parker, on the California side, a formation called by Lee[e] Chemehuevis gravel was noted. Here the gravels are 100 to 500 feet thick and form benches extending several miles west. The formation according to Lee is found from the mouth of the Grand Canyon to the Gulf of California. The valleys between the mountain ranges are filled with various kinds of detrital material, and the map of this part of the region is colored as belonging to the Quaternary system. The Temple Bar conglomerate of Lee extends several miles north of Planet along the road to Yucca and fills a great basin termed by him Detrital Sacramento Valley.[f]

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[a] Lee, W. T., op. cit., pp. 17, 18.

[b] Gilbert, G. K., U. S. Geog. Survey W. 100th Mer., vol. 3, pt. 5, 1875, p. 540.

[c] Ransome, F. L., Geology of Globe copper district, Arizona: Prof. Paper U. S. Geol. Survey No. 12, 1903, pp. 47-51.

[d] Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1905, pp. 75-77.

[e] Lee, W. T., op. cit., pp. 44-45.

[f] For description of this valley by Lee see Bull. U. S. Geol. Survey No. 352, 1908, pp. 52, 53.

GEOLOGIC HISTORY.

PRE-CAMBRIAN CONDITIONS.

Granite-gneiss-schist complex.—The oldest and basal rocks throughout the area mapped are derived from granites and quartz diorites which were metamorphosed in pre-Cambrian time into gneisses and schists. The original relation of these rock magmas must, for the present at least, remain unexplained. The field evidence seems to indicate an intimate association of various granitic and dioritic magmas, the primary relations of which subsequent metamorphic processes have so completely changed that a correct solution of the many complexities would involve untold time and detailed study, with only a suggestion of ultimate success.

Sedimentation.—After the crystalline granites, gneisses, and schists had been severely eroded and partly base leveled, the area was submerged, and several thousand feet of sediments that formed limestone, sandstone, clay, and arenaceous shales were deposited. Basic rocks were intruded or flowed out over these sediments, the results of which are now present in the area as amphibolites. The less resistant of this series were made schistose by regional dynamometamorphism, which is supposed to have taken place during pre-Cambrian time, with resulting argillites and quartz-mica schists. The sandstones were changed to quartzites, and in one or two localities the limestone became dolomite, although in the majority of cases it was simply changed into a crystalline condition.

MESOZOIC (?) CONDITIONS.

Granite intrusion.—At the time of the granite intrusion, which is provisionally treated as of Mesozoic age, the pre-Cambrian rocks had been elevated and erosional processes had been at work during a large part of Mesozoic time, whatever sediments were deposited during former periods having been stripped off, with the result that great valleys were excavated and then filled with detritus and mountain ranges were carved out with bold relief. The intrusion of the granite seems to have affected in only a slight and very local way the physical history of the rocks, the intrusion being confined to the southwestern part of the Harcuvar and the Harquahala ranges and apparently having taken place with only a slight overlying pressure. The results of contact metamorphism caused by the injection of this magma will be discussed in another place.

TERTIARY AND QUATERNARY CONDITIONS.

Volcanic activity and extensive erosion, accompanied by the deposition of much detrital material, mark the Cenozoic history of the region. Flows of andesite and rhyolite, of which only remnants of the older phases now remain, were followed by extensive erosion and subsequent flows of andesite and olivine basalt, the last probably being of Quaternary age. During Tertiary and Quaternary time thick deposits of breccia and conglomerate were laid down and frequently directly on top of pre-Cambrian rocks, showing the tremendous erosion which had taken place during preceding periods. Willis T. Lee [a] gives an account of the geologic events which occurred during Cenozoic times and which the present writer will not dwell upon because of their lack of connection with the ore deposits of the region.

EFFECTS OF METAMORPHISM.

REGIONAL DYNAMOMETAMORPHISM.

All of the pre-Cambrian rocks in the area have been subjected to dynamometamorphism, with the result that the gneisses, schists, amphibolites, and argillites show very pronounced foliation, and that the limestones, quartzites, and amphibolites evince considerable chemical alteration attendant upon this process. With the former change which has occurred in the rocks the main interest of the economic geologist is centered in the possibility of the connection of this metamorphism with the formation, in the argillites and the intercalated amphibolites, of receptacles for the minute auriferous quartz-siderite veins. These veins are common in the southwestern part of the Harcuvar Range, in the locality of the Arizona Northern, the Yellow Bird, the Desert, and other deposits. The sandstones have been silicified and quartzite has resulted, and in one or two localities limestone has been changed to dolomite.

The effects of dynamometamorphism upon the limestones and the intercalated amphibolites are believed by the writer (whose views on this subject are in accord with those of Waldemar Lindgren) to have been far-reaching and to have played a very important part in the formation of the replacement deposits of copper and iron in limestone. As this subject will be treated at greater length elsewhere in this report, it is only necessary to state here that it is believed that during the regional dynamometamorphism of the area the primary metallic constituents of the diabase, diorite, or gabbro which now forms amphibolite were removed, either by segregation or by the action of solutions, and were subsequently deposited in the intercalated limestones with which such deposits are invariably associated in this area.

CONTACT METAMORPHISM.

The principal results of contact metamorphism are seen in connection with the intrusion of the granite which forms a prominent part of the southwestern extension of the Harcuvar Range. Here epidote, augite, hornblende, albite, actinolite, magnetite, garnet, vesuvianite, chalcopyrite, pyrite, and bornite have been developed by contact metamorphism, and a thick stratum of limestone completely changed to wollastonite was noted. Contact metamorphic minerals have been developed at some distance from this central mass, and it is thought that fingers, perhaps showing differentiation phases of the parent magma, extend for some distance under the surrounding country. The mines of the Cobralla, the Calcite, and the Yuma copper companies' and the deposits of the Mudersbach copper camp all show decided evidence of contact metamorphic phenomena, and it is highly probable that many of the gold quartz veins in the region owe their origin to the solutions accompanying this granite intrusion. Thus far the true contact metamorphic deposits which have been prospected have not been shown to be very extensive.

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[a] Op. cit., pp. 57-67.

PHYSIOGRAPHIC PROBLEMS.

The region contains many exceedingly interesting physiographic problems such as the Colorado River drainage, which has been worked out by Lee,[a] and other equally interesting features which are still unsolved. Especially worthy of study are the relations between the Tertiary and the Quaternary rocks and deposits. Because of the fact that this area was investigated with a view to determining the character of the ore deposits, little or no time was spent on the solution of physiographic problems.

THE MINERAL DEPOSITS.

PERIODS OF MINERALIZATION.

Tertiary.—One period of mineralization is definitely known, namely the Tertiary. The deposit in augite andesite at Bullard Peak is undoubtedly of this age. The mineralization in the Mammoth deposit of the Corona Copper Company probably took place during Tertiary time, although this is not positively known. The Clara[b] and Moro deposits, near Swansea, occurring in tuff and sandstone, are probably of Tertiary age and may represent secondary deposition of material derived from the older underlying pre-Cambrian rocks in which the hematite-copper deposits are located. Perhaps the Blue Slate deposit near the Little Butte represents the same general period of mineralization. The fissure veins of the McCracken, Lead Camp, and Guadalupe type are undoubtedly of comparatively recent origin, but it is not possible to fix their age definitely.

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[a] Lee, W. T., Bull. U. S. Geol. Survey No. 352, 1908.

[b] This deposit is located near Clara Peak and is quite unlike the Signal deposit, which is frequently called the "Clara" because it is owned by the Clara Consolidated Gold and Copper Mining Company.

Mesozoic.—The granite intrusion which is so conspicuous in the southwestern part of the Harcuvar Range is provisionally considered as of Mesozoic age. Connected with this intrusion are contact-metamorphic deposits of the Calcite, the Cobralla, and the Yuma copper companies, which deposits are believed to have been formed during Mesozoic times. The quartz monzonite porphyry which has caused the mineralization at the Mudersbach copper camp may be connected with the intrusion of the same granite, and, if so, this deposit is also probably Mesozoic.

The numerous quartz veins found throughout the area and especially those in the San Marcos, Socorro, Hercules, and Bonanza deposits are likewise believed to have resulted from siliceous ore-bearing solutions accompanying this intrusion of granite, and hence may be provisionally classed as Mesozoic.

Pre-Cambrian.—The deposits considered as belonging to the pre-Cambrian era are believed to have been formed at separate periods, and they represent several different types. The hematite-copper deposits, occurring in limestone with intercalated amphibolite or tuffaceous material, like those at Planet, Swansea, Little Butte, Pride, Mineral Hill, and other places are believed to represent the younger phase of the pre-Cambrian deposits. The copper deposits occurring in shear zones in schist, such as the Wardwell & Osbourne, the Carnation, and the Quartz King, are at present considered as of pre-Cambrian age, although there is no actual proof to substantiate this conclusion. The quartz veins in granite and gneiss similar to the Sunshine in the vicinity of the Little Butte are considered as the oldest type of deposit in the area.

Kinds of deposits.—Because of the diversity of the deposits in this area it has been thought advisable in discussing the different types to separate them into groups according to the ore which is most sought for in the respective workings. Hence divisions have been made of the gold, copper, iron, lead, and quicksilver deposits, and a brief sketch of the genesis of the veins of each group will be given.

GOLD DEPOSITS.

QUARTZ VEINS AND SHEAR ZONES IN GRANITE, GNEISS, SCHIST, AND METAMORPHOSED SEDIMENTS.

In this type are included such veins as occur in the Hercules, the San Marcos, the Socorro, and in the Bonanza workings. The last two are somewhat similar in that they lie near the contact of the crystalline rocks and the sedimentary series; the Socorro, however, starts in coarse-grained granite and runs out into sedimentary rocks, while the Bonanza starts in sediments and runs into a crushed granitic rock. The Hercules and the San Marcos resemble each other to a marked degree, and both veins, so far as explored, lie entirely in crystalline gneissic rocks. There is no uniformity in the dip and the strike of these veins, the former varying from 26° to 60°, and the latter from east-west in the Sorocco to north-south in the Bonanza.

The vein filling is primarily quartz and brecciated country rock, and the chief valuable ore has, in the past, been free milling gold. The pyrite of the deposits is oxidized above ground-water level (in general within 200 feet of the surface), and the free gold values are there concentrated. In this connection it is interesting to note the advantage a flatly dipping vein has over one with a steep pitch. For example, in figure 2, A′–B′ represents a vein dipping 63° and shows the lineal extent downward in the zone of surficial oxidation and concentration of gold values as compared with the vein A–B, the same vertical distance above ground-water level, but dipping only 30°. A″–B″ is the length of the vein A′–B′ laid off on the vein A–B.

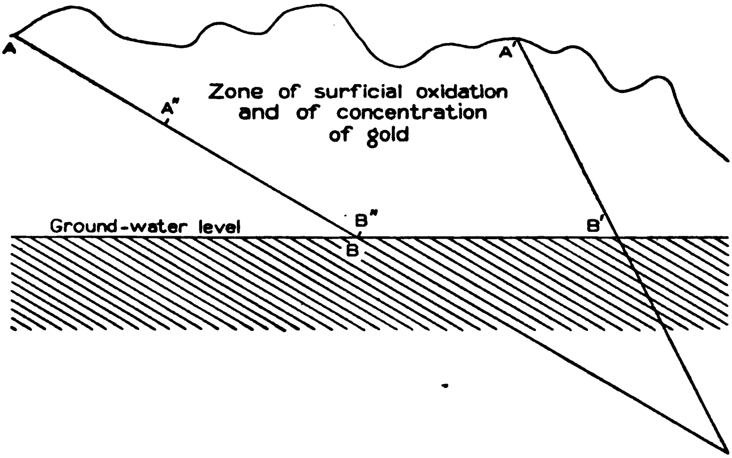

FIGURE 2.—Diagram showing one advantage of a low dip to a superficially oxidized gold quartz vein of the Bonanza type.

The larger the shear zone the more porous the vein, and hence the greater the opportunity for the deposition of pyrite, and also the larger the quantity available for concentration by surficial oxidation. The Bonanza mine affords a good example of large shear zones. The fact that in the past the principal values have been found in the zone of oxidation has led to the supposition that all of the rich parts of the vein would be above the present ground-water level, pyrite being found below. It should be remembered, however, that the present ground-water level may differ from that of earlier times; it may be lower or it may be higher. Therefore there is always the possibility, not necessarily the probability, of finding below the present groundwater level ore that has in the past been concentrated at the lower stand of this level.

In general the higher values in these veins occur in pockets, and even the quartz veins are frequently lenticular. It is believed that the veins were formed by mineralizing solutions accompanying the intrusion of the granite mass in the southwestern part of the Harquahala and the Harcuvar Ranges.

There are a few true fissure veins in gneiss, carrying gold as the principal ore. The Mail Pouch and the Mineral Zone No. 1 were the only ones examined by the writer and these have been described very briefly in another part of the report. The Guadalupe is reported to have been worked for its gold values; surface indications, however, would throw it into the class of lead deposits in fissure veins.

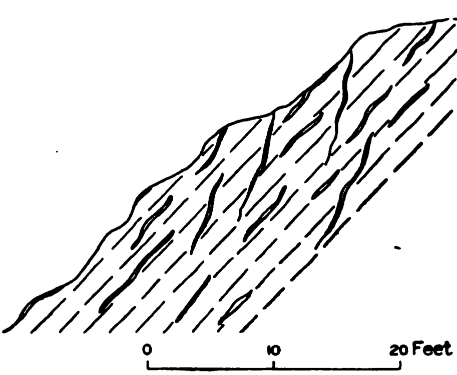

FIGURE 3.—Ideal cross section of a few feet of strata in the vicinity of the Arizona Northern prospect. Shows small quartz-siderite stringers in amphibolite and metamorphosed sediments.

QUARTZ-SIDERITE STRINGERS IN AMPHIBOLITE, SHALE, AND LIMESTONE.

The deposits of this type are found mainly in the southwestern part of the Harcuvar Range and represent irregular masses or gash veins of quartz which are frequently auriferous. The gold values which are so often found in these veins may in part have resulted from superficial oxidation of the pyrite and concentration in place. As these veins are exposed by the erosion gold is concentrated in the placer deposits in the gulches which have been more or less successfully dry washed in the past. Figure 3 shows an ideal cross section of a few feet of strata in the Arizona Northern vicinity, where metamorphosed sediments contain intercalated amphibolite. Here the veins exposed on the surface are generally very small and lenticular and are easily picked out. In a short crosscut in the formation other lenses were exposed, and from this evidence and the general character of the formation the figure is drawn.

These veins contain also some galena and chalcopyrite. Galena has been found in the Harquahala vicinity, and it is possible that the Guadalupe vein is comparable in age to these deposits. It is thought that solutions accompanying the granite intrusion brought in the silica, the carbonates, and the metals, and because of the kind of fissures here present for their deposition formed small gash veins rather than any other type.

THIN FILMS OF GOLD DEPOSITED IN JOINT PLANES IN SHALE.

In several prospects within the area thin films of gold deposited in joint planes in shale were noted. The best-known local examples of this are probably in the Moro prospect, owned by the Clara Consolidated Company, and in the Blue Slate prospect, near the Little Butte. Evidently these deposits are the result of secondary deposition of gold, the original source of which is probably in the near vicinity. In general, deposits of this sort are apt to be of very low grade because of the extreme thinness of the gold flakes; and the saving of the gold is difficult.

COPPER DEPOSITS.

DEPOSITS IN THE PRE-CAMBRIAN SEDIMENTARY SERIES.

The most extensive deposits of iron and copper in this region occur in the series of sedimentary beds and associated amphibolites and chloritic schists which overlie the oldest pre-Cambrian complex of granites and gneisses. The majority of the important examples described in the detailed part of this report are of this character and prominent among them are the deposits at Planet, Signal, various points on Colorado River, and at the Little Butte. These deposits deserve particular mention because of their belonging to a somewhat rare type, the genesis of which is still more or less in doubt. The deposits are generally in two forms. They occur in shear zones in the amphibolitic and chloritic rocks as irregular veins, and in the limestone as replacement deposits, the latter usually appearing at or close to the contact with the underlying older gneisses. Owing to the deep and thorough oxidation which all the deposits in this region have suffered it is often difficult to ascertain the primary constitution of the ore, but it is probable that in all cases the important minerals were specularite, pyrite, and chalcopyrite, containing very small quantities of precious metals. The gangue minerals are quartz, calcite, and, in places, a small amount of siderite. Epidote, chlorite, and amphibole are sometimes present in small quantities. The copper sulphides have been thoroughly oxidized, and the metal now appears mainly in the form of chrysocolla, malachite, and allied oxidized ores. It is believed that the deposits were originally poor in copper and that oxidation has caused their concentration. The concentration of gold noted in a few places is probably also the result of oxidation. In general these deposits contain little gold and silver.

As a rule there are no intrusive rocks in the vicinity with which the deposits could be genetically connected. The association of the copper ores with specularite and their frequent occurrence between limestone and gneiss have often led mining engineers to consider them as of contact metamorphic origin, but there is no valid ground for such classification. A characteristic feature is the association with amphibolitic and chloritic rocks. As these are known to contain copper throughout the world, it is suggested that the metals have in some way been derived by concentration from these rocks. The formation of the deposits probably occurred in pre-Cambrian time and apparently during or after the regional metamorphism which the sedimentary series has suffered. The mineral association described is not one ordinarily occurring in regionally metamorphosed rocks, but, nevertheless, it is believed that they were formed as suggested by a concentration from the amphibolitic rocks during the period of dynamometamorphism. The association of beautifully crystallized specularite with sulphides would indicate deposition at elevated temperature and high pressure. It is also to be noted that the usual position of the deposits is in the basal limestone which generally is covered by the amphibolitic rocks.[a]

REPLACEMENT DEPOSITS IN LIMESTONE.

The Planet, the Signal, and the Little Butte properties represent the principal replacement deposits in limestone. In all of them the gangue minerals are chiefly specularite and quartz with some calcite, and the principal ore minerals are chrysocolla and malachite, which are intimately mixed with the specularite. Occasional specks of chalcopyrite, pyrite, and bornite were noted in these deposits, but they form at present a small portion of the developed ore bodies.

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[a] In discussing the genesis of these ores with Mr. A. C. Spencer the rôle of "water of dehydration as a factor in segregating metallic ores during dynamometamorphism" was considered.

The well-established fact that large quantities of water are set free during dynamometamorphism as the result of crystallization and concomitant dehydration warrants the suggestion that waters of this origin may become a controlling factor in the segregation of metallic ores. In the present case the original crystallization of the diabase or related rock has been destroyed and recrystallization of the constituent minerals has taken place, absorbing some of the water of dehydration by the formation of the micas, epidotes, etc. The rest of the water liberated in this recrystallization could have dissolved and segregated the metallic contents of the original diabase. By circulation through the intimately associated limestone strata, these waters may have been the first agent in depositing the minerals, which, through subsequent oxidation by meteoric waters have been still further concentrated into workable deposits.

Van Hise (Mon. U. S. Geol. Survey, vol. 47, 1904, gives considerable information on the subject of dehydration, but fails to point out the availability of the waters set free by recrystallization for segregating and depositing ores. A. C. Spencer, in discussing the copper deposits of the Encampment district, Wyoming, Prof. Paper U. S. Geol. Survey No. 25, 1907, Chapter III), attributes the origin of certain copper ores to segregation during dynamometamorphism but does not discuss the source of the water involved.

The occurrence of primary specularite intimately associated with quartz and calcite, also believed to be primary, was noted in limestone near the Little Butte property. These minerals follow roughly the stratification planes of the limestone. Specularite having the same general appearance as that noted at the Little Butte was observed in the vicinity of Limestone Mountain between Swansea and Planet. As this iron mineral is more resistant to weathering than limestone large masses of black lustrous specularite are found strewn over the surface of the ground. Associated with the specularite are small crystals of pyrite, which have almost completely altered to limonite. The specularite itself is very fresh and shows little or no decomposition.

One of the most interesting features in connection with the minerals found in this area is the omnipresence of hematite in gossans on top of the veins, in many of the limestone strata replaced by specularite, and generally throughout the region in joints, small cracks, and fissures in the pre-Cambrian granite gneiss schist complex. Especially noticeable are the hematite seams which line all of the openings in the older aplite. In general, this hematite is a hard compact variety, having a dark-red to black color; in places, however, the hematite is soft and earthy and, as exposed in some of the deposits, seems to have assumed this texture along slipping planes where it has been severely crushed.

In any but arid and hot regions this oxidation product of pyrite would be limonite. Here, however, limonite seems to be derived from the oxidation of siderite. The vast quantity of hematite present in the region and its universal distribution as an alteration of pyrite in the older series of rocks is indicative of very extensive oxidation.

SHEAR ZONES IN AMPHIBOLITE AND CHLORITIC SCHISTS.

Among the deposits of this type may be mentioned the Wardwell and Osbourne, the Carnation, and the Quartz King. In general there is a similar geologic section in the vicinity of these deposits. The gangue is principally sheared country rock cemented by quartz, hematite, calcite, and a little siderite. Variable amounts of chrysocolla and malachite form the ore minerals. The shear zones vary from a few inches up to several feet and the ore course is just as irregular.

SHEAR ZONES AND FISSURE VEINS IN GNEISS.

Several different copper deposits in the area are contained in shear zones in gneiss and schist, among which the Viati Mining Company property and the Copper Basin prospects probably afford the best examples. Here the gangue is principally brecciated country rock cemented by quartz and hematite with which is associated a little chalcocite, some cuprite and malachite, and an occasional speck of native copper. The ores are reported to carry also a little gold. These deposits are probably of pre-Cambrian age and may be accounted for by the secondary concentration of very lean primary ores, which may have taken place during the dynamometamorphism of the area.

The principal deposit of typical fissure veins examined belongs to the Cunningham Pass Copper Mining Company and cuts directly across the planes of lamination of the gneiss and schist. The width of the vein varies from a few inches up to 3 or 4 feet and the ore-bearing streak is variable, changing abruptly in places from a barren vein into several inches of ore. The gangue is principally brecciated country and soft red hematite, with some specularite and limonite. Quartz is present in large quantities and occurs in vugs. Occasional veinlets of calcite and barite are present and seem to occupy post-mineral fractures. Above ground-water level the chief ore minerals are chrysocolla and chalcopyrite with some malachite, cuprite, and a little chalcocite. Below water level the chief ore consists of chalcocite associated with much quartz. Chalcopyrite and pyrite are also found in this part of the vein.

The ores have apparently resulted from the leaching and subsequent concentration of values contained in primary pyrite and chalcopyrite.

FISSURE VEINS IN ANDESITE.

The deposit at Bullard Peak is the only one of this type which was examined. It occupies a simple fissure in augite andesite. The vein varies in width from a few inches to 4 feet. The ore is chrysocolla, with which occurs some malachite, a little copper glance, and a small amount of cuprite. Quartz and calcite form the gangue. Some hematite was noted. The deposit is of Tertiary age.

CONTACT-METAMORPHIC DEPOSITS.

Copper deposits originating by contact metamorphism are found chiefly in the vicinity of the granite intrusion which forms a large part of the southwestern extension of the Harquahala and the Harcuvar ranges. Another deposit, located some little distance farther west, seems to owe its origin to the intrusion of quartz monzonite porphyry, which may have some connection with the granite magma already referred to.

Chalcopyrite, pyrite, and bornite have been developed to some extent by contact metamorphism, and deposits resulting from these minerals have been prospected with more or less success. In general the mineralization by copper ore seems to have been exceedingly slight. In the vicinity of the Calcite deposit contact metamorphic minerals are scarce, which fact leads to the supposition that this part of the sedimentary series was intruded when not overlain by a very heavy overburden. About 6 or 8 miles farther north many different contact minerals are present, indicating that this part of the area was under greater pressure than that in the vicinity of Calcite.

IRON DEPOSITS.

Replacement deposits in limestone have already been described under the heading "Copper deposits" (p. 41), and the reader is referred to that description for the genesis of these replacements.

Another type of replacement in limestone exists in the Iron mine south of Bouse. Here, however, the character of the ore is decidedly different from that found in connection with the intercalated amphibolite. The limestones are only partly replaced and appear to form very impure hematite containing much calcareous and siliceous material, which shows practically all of the sedimentary characteristics of the rock which it replaces. Jasper is found in large quantities in the vicinity, and the Tertiary acidic intrusives which cut through the limestones may be responsible for the mineralization.

LEAD DEPOSITS.

Several deposits carrying lead ore were examined, among which the McCracken was by far the most prominent. The veins are probably comparatively recent and may belong to the Tertiary period of formation.

The gangue in the McCracken veins consists principally of carbonates and sulphates with some silicates cementing the fragments of schist and quartz. The carbonates are principally calcite and siderite, with which is associated some dolomite, the former being stained by iron and manganese in such a way that many colors result, the pink-stained calcite closely resembling rhodocrosite. Barite is the principal sulphate present and occurs in large quantities. The most conspicuous ore mineral is galena, which is reported to be argentiferous. Cerusite and anglesite are probably present in substantial amounts.

South of Bouse, in a deposit commonly called the Lead Camp, the vein has a gangue of quartz which contains some galena and is also slightly mineralized with chrysocolla and malachite.

The Guadalupe vein consists of pure white quartz containing many veinlets of siderite, which are said to be auriferous. Galena is found in places in the vein and appears to occur mainly in pockets.

QUICKSILVER DEPOSITS.

Only one deposit containing cinnabar was examined, and this belongs to the Colonial Mining Company at Cinnabar. Here a shear zone, varying in width from a few inches up to several feet, cuts across a sedimentary series of fine-grained quartz-mica schists. This zone is sparsely mineralized with cinnabar. The gangue is highly siliceous and is cut by small stringers of calcite and siderite. The ore in places is conspicuously marked by green carbonate of copper, and gold and silver also are reported from the deposit. Magnetite is a prominent feature in one type of the schists in the vicinity. It has been suggested [a] that the cinnabar has been derived from mercurial tetrahedrite.

DESCRIPTIONS OF MINERAL DEPOSITS.

GENERAL STATEMENT.

Deposits of gold, copper, lead, iron, and quicksilver are found within the area. The mining districts in the region, as shown by the official records of the county clerk of Yuma County, are outlined in figure 4. For the convenience of those most interested in the mineral deposits of this part of Arizona, properties in contiguous localities will be

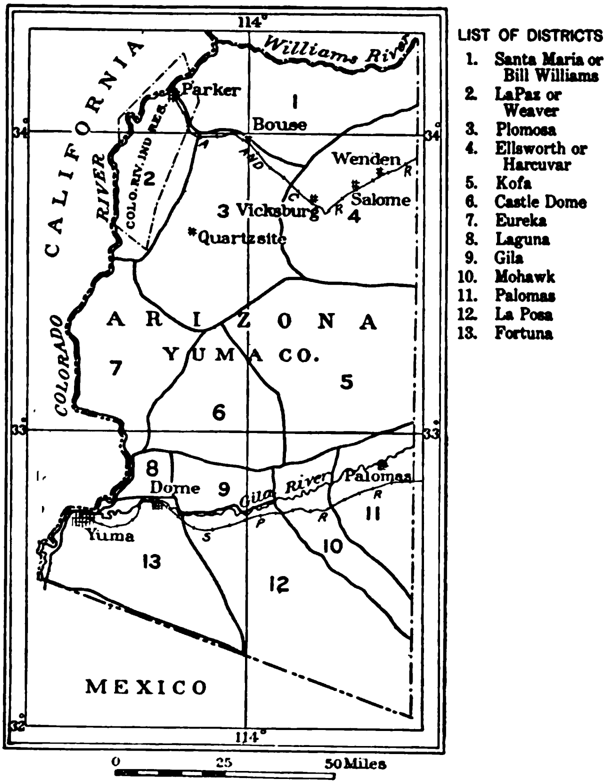

FIGURE 4.—Map of Yuma County, Ariz., showing mining districts, as outlined by the county clerk.

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[a] Bancroft, H., Notes on the occurrence of cinnabar in central western Arizona: Bull. U. S. Geol. Survey No. 430, 1910, pp. 151-153.

described together. The geographic divisions which seem most natural are as follows:

- A. Deposits in the vicinity of Williams River:
  1. Planet.
  2. Mineral Hill.
  3. Clara Consolidated.
- B. Deposits along Colorado River:
  - On the California side—
    1. Viati Mining Company.
    2. Copper Basin.
    3. Bowman's.
  - On the Arizona side—
    4. Quartz King.
    5. Billy Macks.
    6. Carnation.
    7. Wardwell & Osbourne (W. & O.).
- C. Deposits in the Dome Rock Mountains:
  1. Valensuella.
  2. Mariquita.
  3. Colonial Mining Company (Cinnabar).
  4. French American.
  5. Placer deposits.
- D. Deposits in the Plomosa Mountains:
  1. New York Plomosa.
  2. Guadalupe.
  3. Lead Camp.
  4. Mudersbach Copper Camp.
- D. Deposits in the Plomosa Mountains—Continued.
  5. Iron Mine.
  6. Little Butte and vicinity.
- E. Deposits in the southwest end of Harcuvar Range:
  1. Yuma Copper Company (I. & A.).
  2. Yellow Bird.
  3. Arizona Northern.
  4. Desert.
  5. Calcite.
  6. Cobralla.
- F. Deposits in the southwest end of Harquahala Range:
  1. Bonanza (Harqua Hala).
  2. Golden Eagle.
  3. Hercules.
  4. Socorro.
  5. San Marcos.
- G. Miscellaneous deposits:
  1. Cunningham Pass vicinity.
  2. Bullard Peak vicinity.
  3. Corona vicinity.
  4. Planet Peak vicinity on the southwest.
  5. McCracken vicinity.

DEPOSITS IN THE VICINITY OF WILLIAMS RIVER.

The deposits which are to be described under this heading form a natural group by proximity and lithologic similarity. The Planet and the Mineral Hill deposits are separated from each other by a distance of only 2 or 3 miles and from the Clara Consolidated properties at Swansea by a distance of 9 or 10 miles in an air line. They are located in the Santa Maria [a] (or Bill Williams) mining district, in the Williams Mountains a little south of Williams River.

The rocks in the vicinity of all of the deposits are mainly of the pre-Cambrian granite gneiss schist complex overlain by metamorphosed sediments with intercalated amphibolite, all of which are in places covered by volcanic material of a much later age.

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[a] See map of mining districts compiled from official records by the county clerk, Yuma County, figure 4 of this report.

PLANET COPPER MINE.

GENERAL DESCRIPTION OF THE MINE.

Location and means of access.—From the viewpoint of natural surroundings most conducive to mining operations the deposits worked by the Planet Copper Company are situated in one of the most favorable parts of central western Arizona. Williams River, less than a quarter of a mile from the company's office, affords a plentiful supply of water, and the large trees growing upon the banks of this stream will furnish the necessary mine timber for some time to come. The 700-ton smelter at Swansea is only 9 or 10 miles distant in an air line and may afford fairly convenient smelting facilities. The wagon haul between the two places over the present roads is, however, of the most difficult nature.

Planet is situated on the north bank of Williams River, 21½ miles north of Bouse, the distance by wagon road being considerably greater (28 miles). At present the transportation facilities between the two places are of the crudest kind, a stage making the trip to Planet three times a week, coming one day and returning to Bouse the next. It is hoped that the Arizona and Swansea Railroad will make the problem of transportation a simpler and cheaper one than it has been in the past.

History.—The workings at Planet have been referred to by various authors who have written on the mineral wealth of Arizona, and these deposits seem to have been among the best known in the early days of mining in this territory. According to Patrick Hamilton[a] the Planet mine was discovered in 1863, and by the year 1884 had shipped over 6,000 tons[b] of high-grade copper ore to San Francisco. This ore was hauled to Aubrey on Colorado River and was then shipped down that stream to its mouth, most of the ore being sent from there to San Francisco, Cal., although some of it was transported to Swansea, Wales.

One of the oldest smelters in Arizona is located at Planet, having been erected in 1884. Previous to this an adobe furnace had been used to some extent in smelting the ores. The slag dumps from both furnaces are reported to contain upward of 5 per cent copper.

Claims.—Thirty-one lode claims, 3 placers, and 2 mill sites constitute the land holdings of the Planet Company. Survey for patent was being carried on in April, 1909.

Development.—The principal development work on the Planet properties consists of an inclined shaft, No. 1, the first 40 feet of which pitches 45° and the remainder about 15°. This shaft has an elevation of 750 feet at the collar, and is 700 feet long, with short drifts north and south of it, one drift 465 feet long southwest, and crosscuts and stopes, making up a total of about 2,500 feet. Shaft No. 2, started at an elevation of 950 feet, is a double compartment vertical shaft 9 feet by 4½ feet in the clear, and has been sunk to a depth of 350 feet from the top of the ridge into which the inclined shaft penetrates, connection affording good ventilation being made with the inclined shaft workings by an upraise from one of the south drifts (No. 7) near the end of the incline.

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[a] The resources of Arizona, 1884, p. 240.

[b] According to H. C. Hodge the shipments to San Francisco up to 1877 amounted to 8,000 tons of copper ore. See Arizona as it is, p. 69.

Numerous other shafts and inclines have been sunk, drifts and crosscuts run, and a great many open cuts made.[a] These are a valuable aid to the study of the geology of the region, but they do not show very much of the ore bodies which they have been started to develop.

Equipment.—The machinery consists of two gasoline hoists (one 22 horsepower and the other 12 horsepower), a diamond drilling plant, and a 5-drill air compressor and engine. The 36-inch blast furnace, which was erected in 1884, has not been operated for some time nor has it been dismantled, and it appears to be in fairly good condition. A photograph of this smelter is shown on Plate II, *A*.

TOPOGRAPHY.

Viewed southward from a point a short distance north of Williams River, the hills in the vicinity of the Planet workings are seen to form a series of three long, narrow ridges all pointing northwestward and separated from each other by steep-sided canyons draining in the same direction. The ridges increase in height from the most northeasterly, which is low and rises only 100 feet or so above the river, to the last ridge on the southwest, which culminates in Jones Peak, the top of which has an elevation of 1,200 feet, or 600 feet above Williams River. The steep sides of these ridges afford admirable exposures of the geological relationships existing in the locality, and are also valuable as an aid in the exploration of the ore bodies, although in the erosion of the area large parts of the deposits have no doubt been destroyed.

GEOLOGY.

Rocks.—The rocks in the vicinity of Planet are considered to be pre-Cambrian. The lowest formation is granite gneiss, which is overlain by thin bands of limestone intercalated with amphibolite, on top of which rest massive limestone and a series of arenaceous shales, metamorphosed into fine-grained quartz-mica schists. The general lithologic similarity in the sections near Signal and Planet is a feature worthy of remark. A geologic and topographic map and a cross section in the Planet locality are given in figures 5 and 6.

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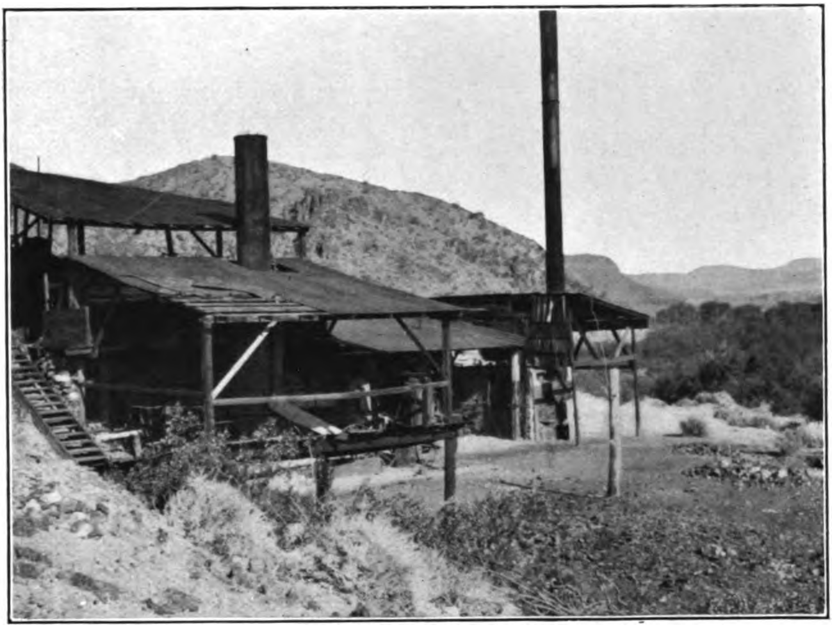
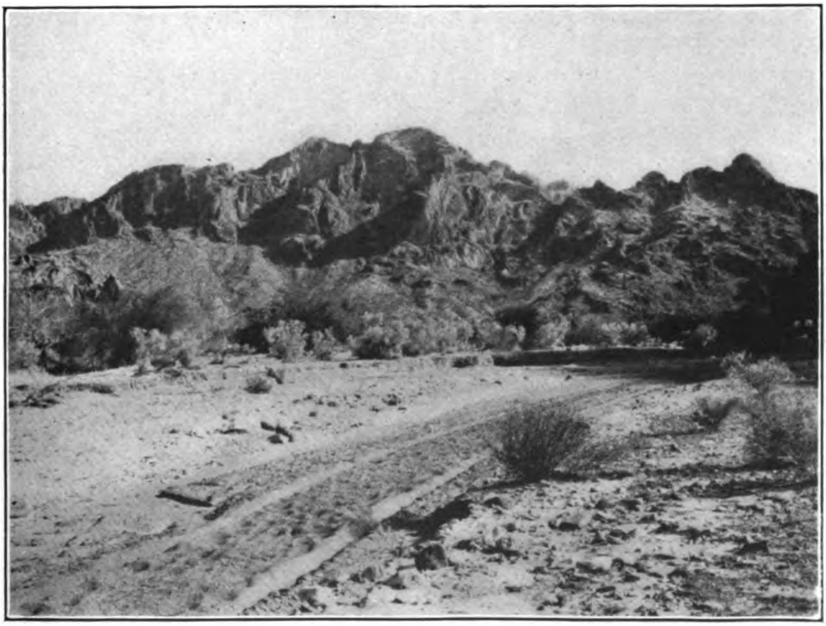
[a] In the prospectus issued by the company 6,000 feet of underground development work are claimed.



A. SMELTER AT PLANET, ARIZ.



B. MOUNTAIN OF GNEISS AND SCHIST ON WILLIAMS RIVER 1 MILE WEST OF PLANET.

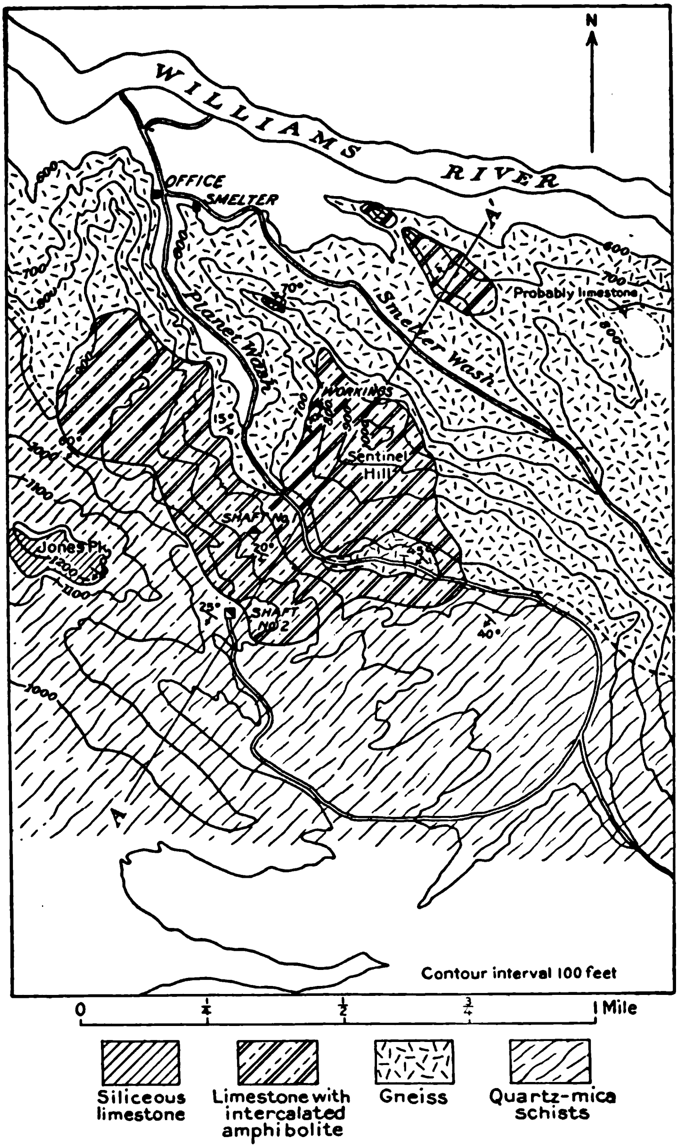


FIGURE 5.—Topographic and geologic sketch map of the vicinity of Planet.

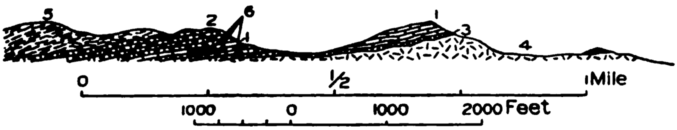


FIGURE 6.—Cross section of the hills in the vicinity of Planet along the section line A–A' of figure 5: 1, Limestone; 2, limestone with intercalated amphibolite; 3, conglomerate; 4, gneiss; 5, quartz-mica schists; 6, known ore bodies in this section, extent undetermined.

Gneiss.—Reference to the same figures will show the distribution of gneiss in the immediate vicinity of the Planet deposits, where it extends south from the river for a distance of several miles and is the basal rock throughout this section; in places it forms prominent mountains, as may be seen by reference to Plate II, *B*. Here the foliated structure is very pronounced in places and the general dip of the lamination planes is between 15° and 30° SE. The rocks are locally both fine grained and extremely coarse grained, the gradations from one type to the other being imperceptible. Chloritization seems to have been extensive in some of the gneisses and epidote is present in large amounts. Quartz and feldspar crystals form the main part of the rock, and the color of the gneiss seems to be due in large part to the kind and amount of the latter mineral present. Some coarse-grained pink gneisses are very prominent in this locality, although the whitish fine-grained rock is the more prevalent. Some faulting has taken place in these rocks, but not nearly as much as would be supposed from a cursory examination of the relation of the overlying sediments to the older gneisses. Before the limestone and the arenaceous shales were deposited on top of the gneiss erosion had trenched the crystalline rock, and contact between the two formations is therefore decidedly irregular and when viewed in a section along the strike of the sediments shows apparent but deceptive evidence of faulting. In general these are simply unconformable contacts, although at one place on the Ella Belle claim there may be some displacement in the series. When the land was submerged, the sediments deposited filled up these depressions in the surface of the gneiss, and subsequent stream erosion has exposed many of the irregularities of the old surface, so that now it is possible to see in places the irregular contact between the two formations. Erosion has been so active, however, that much of the sedimentary series is entirely removed, and with it the evidence of its former continuity and presence in the old dissected lines of drainage.

Aplite and diabase dikes are universally present in the gneiss series.

Limestone with intercalated amphibolite and fine-grained quartz-mica schist.—A series of metamorphosed sediments with intercalated amphibolite rests unconformably on top of the eroded surface of the older granite gneiss. The whole sedimentary complex strikes northwest, dips 15° to 60° SW., and occupies in this vicinity all of the area southwest of the Planet workings, where the total thickness of the series is approximately 900 feet. The lower 200 feet of this complex is composed of thin bands of limestone with intercalated amphibolite resting upon a limestone conglomerate 20 or 30 feet thick, which is locally silicified and composed mainly of bowlders of limestone, quartz, and gneiss. Resting unconformably on top of this series is about 100 feet of a more massive limestone which seems to be free from amphibolite and in which no ore values were noted. Above the massive limestone is a series of fine-grained quartz-mica schists about 600 feet thick, which dips 60° SW. near the base of Jones Peak, but gradually flattens near the top of this peak and southeast along the strike, so that the dip is approximately 20° to 25° SW. in the vicinity above the workings. These schists are likewise slightly unconformable upon the underlying rock, which in the center of the area near the workings is the massive limestone; to the northwest and the southeast the basal gneiss lies directly below the schists.

The limestones are brownish in color, are of fine texture, and the massive variety contains 44.63 per cent lime (CaO) and 2.11 per cent magnesia (MgO). The schists are all fine grained, vary in color from silvery white to gray, red, brown, and green, and are composed chiefly of quartz and white mica, much of the latter presumably having been developed by the alteration of the feldspars. Much chlorite is present in some of the schists, giving them a decidedly greenish tone; some of them might possibly be classed as chlorite schists. Iron oxide has stained other schists in various ways, so that the series presents a variegated appearance. The amphibolite has varying green colors and is usually rather soft, being composed largely of some amphibole mineral associated with a little quartz and much chlorite and talc. Small quartz veins are present in all of the rocks, and an iron cap of hematite is found in many places associated with the limestones. These show only partial replacement by iron and frequently almost entire replacement by silica.

Other geologic features.—Quartzite is found west of Planet Wash, three-fourths of a mile southeast of the inclined shaft No. 1, at an elevation of 700 feet, where it dips southwest at an angle of 40°. Gold is reported as having been found in this formation in values as high as $5 per ton, this presumably occurring along the joints of the quartzite, where occasional copper stains are visible. The rocks in this area dip approximately 40° S. 40° W., and the sequence is as follows: Amphibolitic schists rest on top of the gneiss. These are covered by massive limestone free from amphibolite, over which is found siliceous limestone. Upon this is a conglomerate of quartzite and siliceous schist fragments, over which occurs the quartzite. The section varies considerably along the strike, and parts of it are lacking in places, probably due to deposition upon old erosional surfaces, and, locally, under shallow water conditions.

ORE DEPOSITS.

General statement.—The main developed ore bodies occur just above the contact of the underlying gneiss with limestone, the latter being replaced by hematite, which carries uncertain amounts of copper. In thickness the deposits vary from a few inches to several feet, depending upon the amount of replacement which has taken place in the limestone.

Vertical shaft (*on Bill Williams claim*).—According to the log of the new vertical shaft on the Bill Williams claim three distinct ore bodies were cut in sinking 350 feet through the metamorphosed sediments, which dip 20° to 25° SW., all of them being above the contact with the crystalline gneiss. As the shaft was timbered, an examination of these ore bodies was impossible, and so the information on distances, vertical extent of ore bodies, and assays has been taken from the prospectus issued by the company.

The first body of ore was encountered 170 feet below the collar of the shaft, where about 5 feet of "iron lime" is recorded. This is probably partly replaced limestone. Below this the company took a sample from the interval between 175 feet and 180 feet, which they record as containing 5.56 per cent copper and 48 per cent iron. From the distance 180 feet below the collar to 185 feet the ore body is reported as containing 3.4 per cent copper. Specimens found on the dump from this shaft showed that this first ore body is composed almost entirely of highly replaced limestone, containing hematite in large quantities and a little chrysocolla associated with limonite deposited in the fractures of the ore. Malachite is present in small quantities.

The second ore body cut in the vertical shaft was penetrated at a depth of 230 feet below the collar. At this place the management report 7 feet of ore, averaging 4.77 per cent copper and $1 in gold per ton, and from 237 feet to 254 feet the assay is given as 8 to 9 per cent copper and gold ranging from a minimum of 40 cents to a maximum of $3.30 per ton. A sample of this ore from the dump shows almost massive hematite partly altered to limonite, with copper stains on slickensided surfaces; the remnant of the replaced rock is highly siliceous, and a little quartz is present in the ore.

At a depth of 290 feet the log of the shaft shows a massive body of iron ore, which is 20 feet thick and which caps a 15-foot body of ore running from 5 to 8 per cent copper. This last body has the same relation to the underlying gneiss as have the rest of the developed ore deposits of the Planet group. Specimens of this ore show massive hematite with a scattering of malachite, and also a very siliceous breccia cemented by the various oxides of iron, with a small amount of copper carbonate.

Although these ore bodies were cut in sinking the shaft, no development has been done on them, and therefore the principal consideration will be devoted to parts of the Planet group which have been more or less thoroughly prospected.

Inclined shaft No. 1 (*on Planet claim*).—The inclined shaft started on the Planet and run through the Mark Hanna and the Bill Williams claims represents the most continuous development done on any of the Planet deposits. As already stated, this shaft has, with the various laterals, 2,500 feet of underground workings. For the first 40 feet the incline pitches 45°, and then the dip changes rather abruptly to 15° SW., which is the grade for the rest of the 700 feet to the end of the shaft. Throughout the present incline the main values occur in a limestone conglomerate, locally silicified and containing bowlders of limestone, quartz, and gneiss, and resting on top of the old eroded gneiss, the surface of which apparently dips about 15° S. or SW. The sediments rest on top of this gneiss and dip 20° to 25° SW., and the incline follows the general line of contact between the two formations. Hematite is prominent and seems to contain considerable copper, the latter being present both as carbonate and sulphate. Occasional crystals of pyrite ranging in size from $\frac{1}{32}$-inch up to $\frac{1}{2}$-inch cubes, and the omnipresence of the sulphate of copper form very noticeable features of the deposit. The ore body ranges in thickness from a few inches up to 6 or 7 feet, as shown by the various upraises and winzes cut from the short laterals of the incline, and extends for a known distance of 700 feet southwest of the shaft collar and presumably continues along the contact to a greater distance. Ore from the dump of this incline shows principally hematite, with considerable malachite, some azurite and chrysocolla, and the black oxide of manganese being prominent on some specimens.

Mr. H. A. Keller sampled these workings in 1907, and the results have been published by the Planet Company. These show that the average copper content of the ore body varies from 2 to 6 per cent with occasional values of 11 per cent.

Two general samples from the ore dump of the inclined shaft, according to Mr. Keller, gave the following analyses:

Analyses of ore from inclined shaft No. 1, Planet copper mine, Yuma County, Ariz.

	1.	2.	Average.
Copper (Cu)	6.29	5.30	5.8
Silica (SiO_2)	39.91	38.81	39.36
Iron (Fe)	32.00	30.62	31.31
Alumina (Al_2O_3)	.....	.....	1.83
Lime (CaO)	.56	.20	.38
Sulphur (S)	4.07	3.85	3.96
			82.64

Mr. Keller gives the average width of the ore body as 4 feet 3 inches and its average copper content as 5.90 per cent. The accuracy of this statement seems well supported by an examination of the property.

Two analyses of the clear slag from the old dump are reported as follows:

Analyses of slag from inclined shaft No. 1, Planet copper mine, Yuma County, Ariz.

	1.	2.
Silica	34.5	38.0
Iron oxide (FeO)	48.8	45.2
Copper	5.2	5.7
Alumina	10.0	10.6
Lime (CaO)	1.2	1.5
Magnesia	None.	None.

A level started at the base of the steep 40-foot incline and driven almost due south for a distance of 160 feet is, beyond the 120-foot station, where a short incline is sunk, entirely in hematite. Apparently this ore body is a short distance above the basal gneiss and represents a complete replacement of the limestone strata which lie on the gently southward dipping surface of the gneiss. Some 60 feet west this level is prolonged from the west branch and extends for a distance of 480 feet southwest, the whole of the drift being in hematite, analyses of which have been made by the Colorado Fuel and Iron Company and the results published in a report to the Planet Company by H. A. Keller. Two of their analyses are as follows:

Analyses of hematite from inclined shaft No. 1, Planet copper mine, Yuma County, Ariz.

[H. A. Keller, analyst.]

		1.		2.
Iron (Fe)	65.48		60.42	
Iron (Fe_2O_3)		93.54		86.31
Silica (SiO_2)		7.00		12.87
Phosphorus		.031		.018
		100.571		99.198

Other workings.—More or less development exists on numerous other claims, all of which show the deposits to be of a very similar nature, being replacements in limestone by iron and copper minerals. The latter, however, are more siliceous in the workings on Sentinel Hill and farther east than those found in the ore body opened by shaft No. 1, chrysocolla forming the principal copper ore in the Blue Bird, the Palmetto, and the Sentinel Hill deposits. Specularite is present in large amounts, with malachite and the black oxide of manganese forming an important part of some of the surface exposures. A mineral was noted in a specimen from the dump of the Palmetto prospect which very closely resembles the description of morencite, a mineral discovered by Lindgren in the Clifton-Morenci district.[a]

Origin of the ores.—The chief ores in these deposits consist of aggregates of foils of specularite (part of which is probably primary), a little limonite, some malachite, and an occasional speck of pyrite.

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[a] Lindgren, Waldemar, Prof. Paper U. S. Geol. Survey No. 43, 1905, pp. 115-116, 178.

With the exception of the minute quantity of pyrite and the still smaller quantity of bornite and chalcopyrite seen in a few of the specimens, the deposits are formed of oxidized material, a large part of which has presumably resulted from the alteration of pyrite and chalcopyrite. This theory is upheld by the omnipresence of crystals of soluble sulphates found scattered throughout the ore body and probably resulting from the action of the sulphuric acid (liberated from pyrite in its decomposition) upon limestone, which is itself in places almost completely replaced by ore minerals. There is a total lack of contact metamorphic silicate minerals, as well as an absence of any intrusive (other than the rock which now forms amphibolite) of later date than the limestones, and it seems highly improbable that these deposits are of contact metamorphic origin.

The deposits seem to follow the bedding planes of the limestone and the general line of contact between this formation and the underlying gneiss. It is possible that during the long-continued alteration which these ancient rocks have undergone the iron and copper values, which occur in normal diabases and associated basic rocks, were concentrated or at least taken into solution and subsequently replaced the limestone with which the amphibolite is so intimately associated in this as well as in similar deposits within the area. The occurrence of fairly large bodies of hematite, almost invariably associated with the silicates and carbonates of copper in rocks which are essentially limestones with intercalated amphibolite, and the total absence of any intrusives (other than the rock which now forms amphibolite) of later date than the limestones, are all indicative of a local origin for the ores.[a] Although the extent of the ore deposits varies considerably in geologic sections of this sort, similar relations were observed in the following places: Planet, Swansea, Carnation, Battleship Mountain, Limestone Mountain, and Pride prospect.

MINERAL HILL DEPOSITS.

GENERAL DESCRIPTION.

These deposits are situated on the slope just west of Mineral Wash, 2½ miles from Planet and over a mile up the wash from Williams River. The group of claims comprising the Mineral Hill deposits which are to be discussed have been prospected in a general way, although there is no permanent camp located at the place, and no active development was going on at the time of the writer's visit. The upper workings are admirably situated for tunneling, and shafting would not be a necessary feature of the operations above the wash level. Water has to be hauled from Williams River, timber is practically absent in the immediate vicinity, and fuel would have to be hauled for large operations.

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[a] For a discussion of the genesis of these ores see page 41.

The Continental prospects, which are in this vicinity, were not examined for lack of time.

Means of access.—The Mineral Hill deposits are almost as difficult of approach as the Planet. Bouse and Parker are nearly equidistant from Mineral Hill in an air line, the former being 21½ miles due south and the latter 17½ miles southwest. By wagon road, however, the distance to both places is increased at least 4 or 5 miles. The completion of the Arizona and Swansea Railroad makes it possible to shorten the wagon haul considerably, and, in the future, should the property become productive, no doubt a route to this railroad will be chosen for transportation.

TOPOGRAPHY.

Near the deposits Mineral Wash has an elevation of a little over 500 feet. On the west of the wash, hills rise somewhat steeply to an elevation of 1,100 feet, and in one of these hills the deposits occur. The topography in the vicinity is characterized by steep-sided but shallow canyons and isolated hills. A short distance farther west at an elevation of 1,500 feet a basalt-covered plateau extends toward Colorado River.

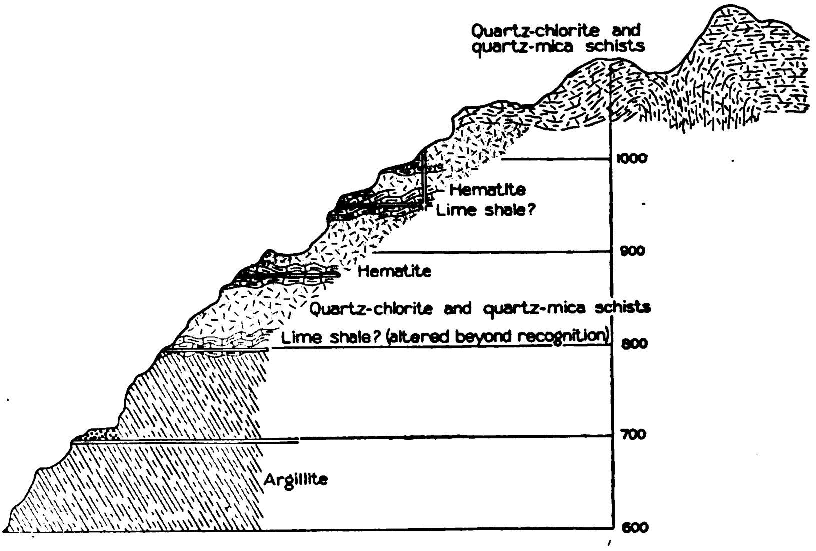
Quartz-chlorite and quartz-mica schists
1000
Hematite
Lime shale?
900
Hematite
Quartz-chlorite and quartz-mica schists
Lime shale? (altered beyond recognition)
800
700
Argillite
600

FIGURE 7.—Ideal section of Mineral Hill.

GEOLOGY.

The rocks at Mineral Hill (see fig. 7) are a basal series of argillite having a thickness of several hundred feet, upon whose eroded surface rests a series, 300 feet thick, of arenaceous shales, metamorphosed into fine-grained, quartz-mica schists of various colors, interlaminated with small amount of very impure limestone. Intimately associated with e schists is a metamorphic rock which resembles a quartz chlorite schist, the field relations suggesting intrusion of the rock into the series. Microscopic examination of thin sections shows, however, that the chloritic rock is of unquestionable clastic origin, so that its intrusive appearance is manifestly deceptive. A satisfactory explanation of the relations existing here is difficult. This metamorphic rock occupies about four-fifths of that portion of Mineral Hill which is above the elevation of 700 feet.

It is possible that during the period of regional metamorphism when the schists were folded and faulted, the pressure upon them was so great that they assumed locally, before recrystallization, the relation to the quartz chlorite schist which makes the latter rock appear as an intrusion into them. It seems scarcely possible for the quartz chlorite rock to have become so plastic that it could have been squeezed into fractures formed in the quartz-mica schists.

The strata which form Mineral Hill are undoubtedly continuous with those resting on the gneiss in the vicinity of Planet, and both series were probably lifted and deformed at the same time. Figure 7 represents an ideal section of the geology of this vicinity.

In general the dip varies from 30° to 50° SW., although above the elevation of 800 feet where the quartz chlorite and quartz-mica schists overlie the eroded argillites the dip is comparatively flat and remains so up to an elevation of 1,050 feet, where the most extreme twisting and contorting of the schists is seen and where the dip changes every few feet.

ORE DEPOSITS.

Workings.—Although only a small amount of development has been done on the ore bodies in this hill, and this of a very scattered nature, there exist nevertheless enough workings to exhibit in a general way the relationship between the geology and the ore deposits in the vicinity.

On the north slope of Mineral Hill there are four short adits, 200 feet or less in length, separated from one another by vertical distances of 100 feet or more. From the upper adit a 40-foot upraise to the surface has been driven. The Mohave Chief and the Norma workings on the southeast slope of the hill were examined in a cursory way, the time being very limited and the developments meager.

Ore bodies exposed by workings on the north slope of Mineral Hill.—An adit started at the elevation of 700 feet and driven 200 feet S. 45° W. passes through surface conglomerate for a short distance; the remainder of the adit cuts fine-grained schists, which dip rather steeply southwest. At right angles to the dip of the schists occur several minor slips which are mineralized to a small extent by chrysocolla.

The second adit in this series is driven 100 feet higher up on the hillside and is 100 feet long. The floor of this working seems to be just above an eroded surface of the schists, and the roof is composed of material which in the field greatly resembles a very much altered and silicified locally brecciated limestone.

A third adit is located at an elevation of 875 feet, and the 100 feet of tunneling exposes a small deposit of hematite in a conglomerate of exceedingly impure lime shale and quartz chlorite schist fragments. So much alteration has taken place that the fragments referred to as lime shale may represent other rocks, the original character of which it is impossible to determine. The ore body here is intimately associated with the conglomerate, and hence of an impure nature. About 25 feet above this level there is another thin band of hematite which occurs between walls of quartz chlorite schist.

At an elevation of 950 feet is found the most promising of the deposits on the north slope of the hill. Here the drift is run about 100 feet, having specularite for a roof and a much-altered, iron-stained rock resembling shale for a floor. An upraise of 40 feet to the surface cuts, above the hematite, quartz chlorite schist which contains a thin layer of lime shale about 25 feet above the level. The specularite and the much-altered shaly rock both contain chrysocolla and malachite in fairly large proportions; in both instances, however, the copper minerals fill fractures which have cut across the iron ore and the altered rock.

A short distance above the highest workings described the schists are greatly contorted, twisted, and buckled. In many places within the area small folds were seen, but not in any other locality were similar results noted on such a large scale. Quartz veins are developed on a small scale throughout the whole series. These are in part lenticular, lying in the planes of lamination, although they generally cut the formation.

Ore bodies exposed by workings on the Mohave Chief and the Norma claims.—A short distance south and west of the openings on the north slope of the hill occurs the deposit opened on the Mohave Chief claim. One of the workings here is a small open cut, the top of which is at an elevation of 950 feet. The work at this point has been done just over the contact of the lime shale with the quartz chlorite schist, and no regularity exists in the deposit. The mineralization occurs in scattered patches. Chrysocolla intimately mixed with brochantite is associated with a jaspery gangue. Just west of the open cut and 25 feet lower there are several small workings which have been started in lime shale or limestone, which is more massive than the greater part of that seen in the vicinity and which is intimately associated with the green quartz chlorite schist rock.

On the Norma claim an adit started in lime shale at an elevation of 800 feet shows a little mineralization in fissures which cut across the ·ntry rock in the general direction of N. 20° W. These fissures are only a few inches wide and not many of them are present in that portion of the rock exposed by the adit.

Paragenesis of the ores.—As at the Planet mine the sulphides have been almost wholly oxidized, and it is difficult to say what the original condition may have been. Here too, probably, some of the specularite is primary, and it is believed that it was associated with pyrite and chalcopyrite. At Mineral Hill the oxidized copper ores appear to be later than the specularite and were in large part deposited in fractures in this iron ore; at the Planet they occur distributed throughout the specularite.

CLARA CONSOLIDATED MINING COMPANY'S PROPERTIES.

PROPERTIES AND LOCATION.

The properties examined belonging to the Clara Consolidated Mining Company are the Signal, the Moro, and the Clara. The last two represent deposits of nature different from that of the Signal, and they are located some little distance to the southeast in a different geologic formation.

Swansea, the name of the locality in which the Signal deposits occur, is the center of the mining and smelting activity of the Clara Consolidated Mining Company. Here the company has recently erected a 700-ton smelter; it has also built railroad connections with its near-by properties and with the town of Bouse, situated on the Arizona and California Railroad about 23 miles a little west of south of Swansea. At the time of the writer's first visit to the properties a few bunk houses, offices, and a store constituted the town. No doubt at the time of writing (March, 1910) Swansea is a more substantial place, for the railroad from Bouse and the smelter have been completed since the prospects were examined in April, 1909. Water is pumped to the property from Williams River, 4 or 5 miles distant, through a 6-inch and a 3-inch main, and timber is shipped in from the outside.

TOPOGRAPHY.

The road from Bouse to Swansea ascends the gentle slopes of the foothills of Williams Mountains, which are so thoroughly covered by débris that only low, gently sloping ridges project above the detrital masses. About 3 miles south of Swansea the country breaks off toward Williams River and the descent of 500 feet to the Signal property is through a rough country, where the rocks are well exposed. In the immediate vicinity south of the Signal deposit a hill of gneiss capped by limestone rises to an elevation of 1,800 feet. Several similarly formed hills are a noticeable feature about 1 mile west, where they attain an elevation of 200 to 400 feet above the surrounding desert, which slopes gradually in the direction of Williams River.

Sharp prominent ridges of gneiss form the mountains south and east, and Clara Peak, a little over a mile to the east and composed of much younger material, rises to an elevation of 2,400 feet, or about 1,000 feet above the general elevation of this part of Williams Mountains.

SIGNAL PROPERTY.

HISTORY.

Prior to July, 1908, the properties, which were at that time united as the Clara Consolidated Gold and Copper Mining Company, belonged to several individuals and companies. Of these the Signal Mining Company had probably done by far the greatest amount of development work, although as a matter of fact this was of very meager extent. According to a legend current in the district Germans worked this deposit many years ago, and in proof of this tale it is said that a German ore car was found in one of the old workings. The writer talked on this subject with Mr. J. W. Johnson, of Mineral Hill, who said that he had left an old wooden car in the workings of the Signal some twenty or thirty years ago, and that this was probably the much talked of "find."

PRESENT CONDITION.

Development.—On the Signal property there are six shafts (see fig. 8 for locations), two inclined and four vertical. Nos. 1, 4, 5, and 6 are vertical, the first having been used as the principal development shaft at the time of the writer's first visits to the property, in the spring of 1909. Shaft No. 1 is down some 400 feet, and levels have been driven at 100-foot intervals, with drifts, crosscuts, raises, etc., aggregating several hundred feet of workings. In September, 1910, this shaft was filled with water and waste up to the 200-foot level, so that it was not accessible for examination below that level. No. 4 shaft was sunk with a view to making it the future working shaft of the property. An examination of figure 8 will show that No. 4 shaft was sunk outside of the ore zone, at a place where all of the ore would have to be trammed back to the shaft in a direction away from the smelter, thereby increasing the cost of handling the ore. This shaft was abandoned at the time of the writer's last visit to the property (September, 1910), and shafts 5 and 6 were being sunk and the underground developments pushed in their direction. Shafts No. 2 and No. 3 are inclined, the former about 45° to 50° N. 22° W. and the latter 65° to 75° N. 45° W. Shaft No. 3 is not now used—this and shaft No. 2 representing older workings on the property. Shaft No. 3 is approximately 200 feet and shaft No. 2 a little over 300 feet deep, the latter being connected with all the main workings of the mine. The development work done to September, 1910, including shafts, crosscuts, drifts, winzes, etc., would amount to approximately 6,000 feet.

Equipment.[a]—Small gasoline hoists for two of the shafts have been installed for some time. A 125-horsepower geared steam hoist is reported to have been ordered for the new working shaft. A 6-drill air compressor furnishes power for the drills operated in the workings from shaft No. 1. Two electric locomotives are used for hauling ore from the shafts to the ore bins.

The smelting plant consists of a 700-ton copper furnace, 44 by 280 inches, opening at the top into a Mitchell steel hood, 10 by 26 feet, which opens into a main flue 8 feet in diameter leading into two balloon flues, each 5 by 7 feet. The brick and concrete dust chamber, 20 feet wide, 12 feet high, and 90 feet long, opens into the steel stack, 150 feet high. The floor of the dust chamber is of concrete, having hoppers for discharging the flue dust into cars underneath. Two blowers to supply the blast for the furnace have been set in place. The foundations are in for the steel converter building, which is to contain a 50-ton electric crane and two stands of copper converters. The blast for these will be supplied by a low-pressure air compressor.

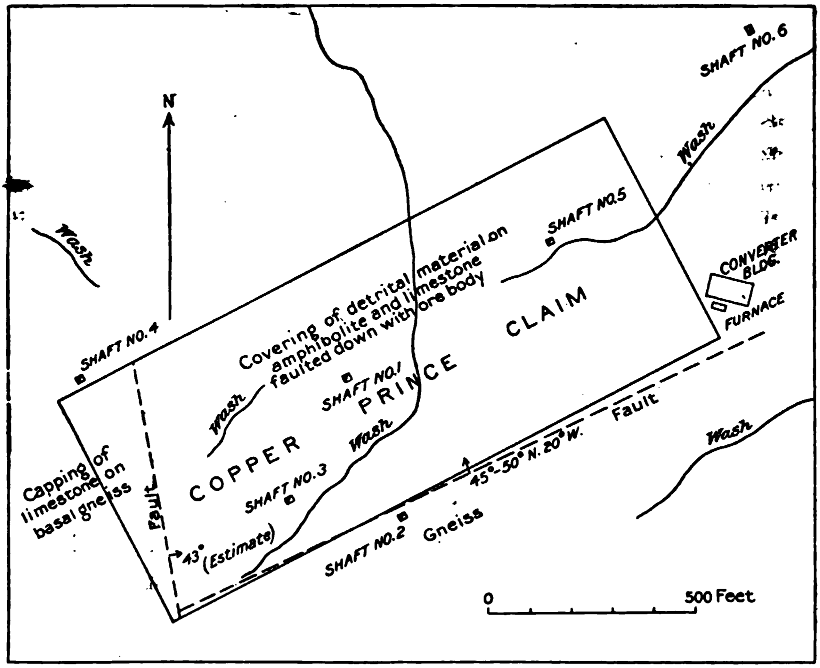

FIGURE 8.—Diagram showing location of shafts and possible surface location of two main faults on the claim containing the Signal ore deposit.

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[a] The information pertaining to the equipment is taken directly from the Mining and Scientific Press, Feb. 19, 1910, p. 299.

A steam electric generator will operate the electric crane and supply power for the trolley lines of ore and slag cars. The converters will be operated by electric power. A crusher, a set of rolls, and a mud mill are being installed for preparing the siliceous ore for converter lining. The charging cars to be used will have automatic weighing attachments for weighing the ore and coke before they are dumped directly into the furnaces.

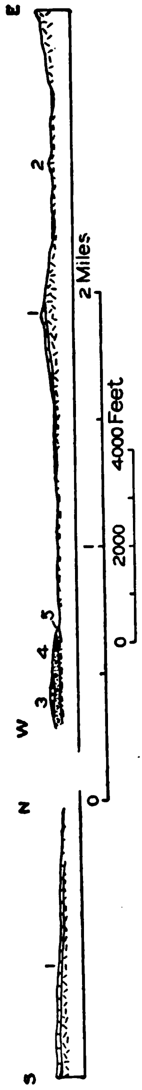

FIGURE 9.—Ideal north-south and east-west sections of the hills south and west of the Signal mine: 1, Limestone; 2, gneiss; 3, andesite; 4, volcanic ash and andesite flow cementing fragments of gneiss, limestone, etc.; 5, platy and shaly limestone.

Production.—At present (March, 1910), there has been no output from the Signal mine by the Clara Consolidated Company. If there was any production previous to July, 1908, it was only nominal.

GEOLOGY.

The country rock at the Signal mine (see fig. 9) is a coarse-grained, rather light colored granitic gneiss, showing some chlorite and epidote along the lines of foliation. In places this rock is compact and fine grained and somewhat resembles quartzite. Locally this phase of the rock has been called quartz porphyry. The schistosity of the rock is nearly flat, though locally it is not at all regular in direction of dip. In the canyon south of the office the general dip of the planes of lamination is 10° to 20° NW., and the strike varies from 35° to 85° NE. The hills south and east of this canyon are composed of gneiss; the pressed feldspars and lenticular quartz aggregates show clearly the igneous origin of the rocks. The low ridge west of the gulch consists of a heavy bench of dark-brown limestone dipping 35° to 40° W. or NW., and resting unconformably on the gneiss. (See fig. 9.) Near the north end of this low ridge there is a small amount of highly siliceous material, which apparently underlies the limestone and overlies the gneiss. This rock is only a few feet thick and has been exposed by the erosion of the overlying limestone. In places this erosion has occurred in such a manner that the siliceous rock appears to have cut through the limestone, although the relations seem rather doubtful. The siliceous rock is a pinkish gray and seems to be composed entirely of silica, vugs or cavities in it being filled with quartz crystals. It is impossible to determine the original character of the rock, but it now appears to be a quartzite, and may here represent the remnant of the basal part of the sedimentary series. The rock just west of the mine and south of the office contains schistose layers of a chloritic amphibolite, conformable with the limestone. The limestone is probably not over 100 feet thick. Farther west and northwest other small hills of limestone and intercalated amphibolite can be seen. Here diabase intrusives cut the formation, and along the contact of the dikes quartz-siderite veins have been formed. One hill a little farther to the southwest than the ones just referred to, and about 1½ miles due west of the Signal office, is composed of quite different rocks. Above a coarse-grained pink granitic rock, which is cut by diabase dikes, comes a series (50 feet or more) of platy and shaly limestone, dipping about 20° a little south of west. Upon this rests a series of deposits, 200 feet thick, composed of volcanic ash and an andesitic flow cementing fragments of limestone, granite, schist, and other rock mostly angular, although some are rounded. The remaining 50 feet of the hill is composed of an andesite flow, which also covers the tops of a few of the hills in the immediate vicinity of the one just described. The tuff and andesite are much later than the underlying rock and are probably of Tertiary age.

At the base of the limestone in the wash lies the ore deposit. As exposed on the surface this represents an irregular replacement in the limestone which extends a short distance along the gulch as a zone about 30 feet wide, containing much hematite, partly crystallized as specularite, and some copper stains, but with no other visible minerals. Here, as elsewhere, the limestone overlies the gneiss and is intimately associated with the amphibolitic schist, which is barren of any mineralization on the surface. The surface of the gneiss as eroded here dips approximately 52° N. Elsewhere this eroded surface changes its plane considerably, the unconformable relation of the sediments and the gneiss making this all the more apparent.

THE ORE DEPOSIT.

Figures 10 and 11 illustrate features of the ore deposit and of its development. The Copper Prince claim is shown in figure 8, which gives approximately the locations of the various shafts, washes, etc. The true position of the two faults is rather uncertain, and their exact surface locations are unknown to the writer. For the sake of reference, however, their approximate position has been outlined. The major part of this claim, it will be seen, occupies a faulted block of country rock whose original position was to the southwest and considerably higher than it is at present. Figure 10 is a tentative cross section of the deposit as developed in September, 1910. Figure 11 represents a hypothetical stereogram of the ore deposit as it would probably appear if it could be viewed from the northeast corner of the claim.

The ore deposit lies in the faulted block of country rock. It is an irregular replacement of the limestone by specularite, with here and there a scattering of chalcopyrite and a small amount of pyrite, associated with some quartz and epidote, the whole being similar in many respects to the Planet ore bodies. The main body of ore is about 90 feet long, and presumably extends above the 145-foot level to the surface. The width of the ore body varies considerably according to the amount of replacement which has taken place in the country rock, perhaps a fair average being from 20 to 30 feet. The western side of this ore body seems to lie along a fault which dips approximately 35° N. 70° E. On all sides of the ore body amphibolite and limestone are found, amphibolite greatly predominating, although in places limestone is conspicuously present. Large limestone bowlders, which are apparently nearly pure calcium carbonate, are found in this ore body. These are covered in part with

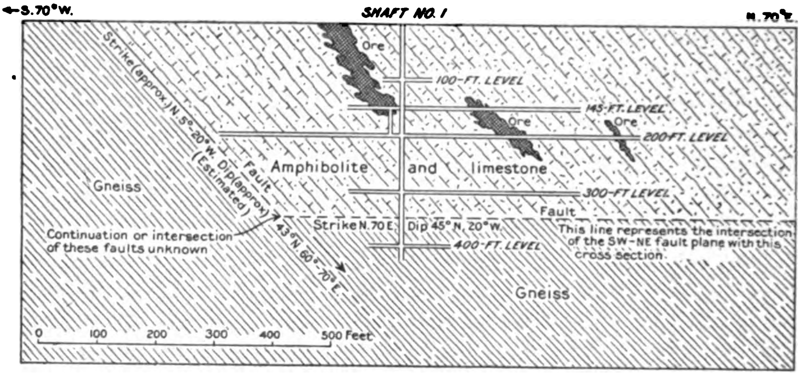

FIGURE 10.—Tentative cross section of the Signal ore deposit as developed in September, 1910.

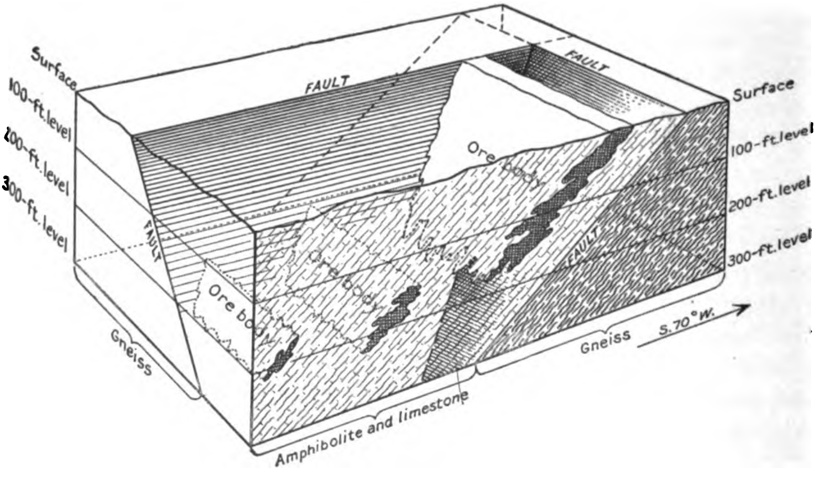

FIGURE 11.—Hypothetical stereogram of the Signal deposit.

hematite crystals, which are intimately associated with amphibolite. Pyrite and chalcopyrite are also present. Specimens from the dump show also some black oxide of manganese. An average assay of the deposit as exposed on the 145-foot level, in drift D 2, would perhaps run 2.5 per cent copper.

Evidences of extreme movement are noticeable, great slickensided surfaces and severe contortion having been observed in most of the underground workings. Viewed underground this movement appears more recent than pre-Cambrian.

Gneiss was found in crosscut No. 205, which is located 70 feet S. 70° W. of shaft No. 3 on level No. 2 and driven in a southeasterly direction, and amphibole was noted in drift No. 203, which is located 150 feet N. 70° E. of shaft No. 3 and driven in a northwesterly direction. This exposes the fault plane or contact of gneiss and the metamorphic series in a remarkably good manner.

As exposed on the surface and in the workings of the Signal mine the ore zone seems to be rather narrow and to be composed almost entirely of specularite, replacing the limestone, with here and there a scattering of chalcopyrite and a very small amount of pyrite. The shear zone, which is so prominent in the workings, is by no means thoroughly mineralized, and there is little probability that it will be found so at depth.

Other ore bodies, similar to those found on the 200-foot level, may be encountered as drifting in a northeast direction progresses. Concentration of ore along slipping planes of the amphibolite was noted in many places, and it is possible that future developments may expose other ore bodies which will prove extensive enough to mine.

ORIGIN OF THE ORES.

Doubtless the origin of the Signal ore body may be attributed to the same causes as those that formed the Planet deposits. In the Signal property later faulting and fracturing is evident, and chalcopyrite, pyrite, and hematite have been introduced in small quantities into the crushed zones of the country rock and in small cross fissures in the gangue and ore.

MORO PROPERTY.

RELATIONSHIPS AND LOCATION.

The property of this name is one of the group owned by the Clara Consolidated Company and its general geologic relationships and similarity of ore deposits are quite analogous to those of the Clara situated only 2 miles northeast. The workings of the Moro are situated in a small oblong hill about one-fourth of a mile wide and three-fourths of a mile long, the base of which is along a rising contact between underlying pre-Cambrian granite gneiss and overlying probably Tertiary sandstone and volcanic tuff. Moro No. 1 tunnel is some 2½ miles southeast of Signal shaft No. 1 and 2 miles a little east of south of Clara Peak. This adit is on the southeast side of the small hill, and is at an altitude of about 1,650 feet.

No. 2 tunnel is a short distance farther up the hill at an elevation of 1,700 feet, and this, as are the others, is located near the contact of the gneiss with the tuff.

No. 3 tunnel is on the west side just below the northwest end of the hill at an elevation of 1,750 feet.

Development.—In April, 1909, the following development work had been done on the Moro group:

Moro No. 1. Adit about 200 feet long and a very short crosscut on a small transverse fissure cutting across the adit.
Moro No. 2. Inclined shaft 50 feet deep, dipping 20° SE.
Moro No. 3. Adit 200 feet long with drifts at right angles to end, one 20 and the other 50 feet long.

No production from the property is known.

GEOLOGY.

As already stated, these deposits occur near the contact of granite gneiss and beds of tuff and sandstone. The relation between the two is unconformable, and they are separated by wide geologic epochs, the gneiss being pre-Cambrian and the sediments no doubt being late Tertiary or Quaternary. Between Moro No. 2 and the divide near the top of the hill, a thin band of probably pre-Cambrian limestone was observed, which is analogous to the covering of limestone on top of the granite gneiss back of the Signal office. At the Moro workings the plane of the eroded surface of gneiss dips southeast, but this dip is only local and was caused by former drainage. At an elevation of 1,900 feet, at the base of the sedimentary series which forms Clara Peak, another band of limestone (probably pre-Cambrian also) was seen overlying the granite gneiss.

ORE DEPOSITS.

The ore occurs above the gneiss in and above the conglomerate which marks the base of the tuff and the sandstone sediments. Scant deposits of the silicate and carbonate of copper, with here and there a little leaf gold, have been made along the joints and small fissures in the sediments. Calcite is abundant in the openings in the rocks and quartz is present in small quantities. A little copper glance was noted in Moro No. 2 and besides the calcite some gypsum. Specularite was not seen, although the red oxide of iron (hematite) is present in many places. The deposits are small, and mineralization is limited.

CLARA PROSPECTS.

The Clara deposits are very similar to the Moro deposits. They are located 2 miles southeast of Clara Peak at an elevation of about 1,450 feet, just west of one of the main washes in the vicinity draining into Williams River. A section from Clara workings to Clara Peak and thence to the limestone hills south of Signal office is given in figure 12. The workings consist of a short adit tunnel at an elevation of 1,450 feet, a shaft some 90 feet deep at an elevation of 1,475 feet, and an adit about 100 feet long with a 10-foot winze at the end, located at an elevation of about 1,500 feet. These developments are all located within a short distance of each other on the east side of a hill about 1 mile wide and two-thirds of a mile long, near the contact of volcanic tuff and sandstone with the older underlying granite gneiss. The first opening shows several parallel joints which form small fissures running north-south and dipping about 80° W., with little or no mineralization. The shaft passes through 20 feet of sedimentaries, dipping slightly northeast, and the remaining 70 or 80 feet is in hard granite gneiss showing no mineralization whatever.

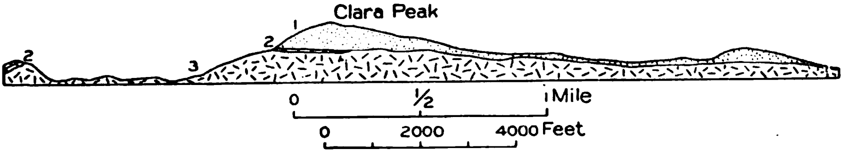

FIGURE 12.—Ideal section from Clara workings to Clara Peak and thence to the limestone hills just south of the Signal office. 1, Volcanic ash and sandstone; 2, pre-Cambrian limestone; 3, gneiss.

The third opening is practically on the contact between the two formations and shows jasper with a little silicate of copper, some minute particles of chalcocite, and iron stains fairly prominent at the breast of the adit. Specularite was not observed in the workings. Here the sediments dip 15° SW. Leaf gold has been reported from these properties; none was in evidence, however, at the time of the writer's visit.

Probably both the Moro and the Clara deposits have resulted from a secondary deposition of material derived from the older underlying rocks which contain the hematite-copper deposits worked in the Signal mine and elsewhere.

DEPOSITS ALONG COLORADO RIVER.

The deposits which are to be described under this heading are more or less scattered and are not of one type, although some similarity exists in the geological sections of the different localities. Of these properties three are on the California and four are on the Arizona side of the Colorado.

PROPERTIES ON THE CALIFORNIA SIDE OF THE COLORADO.

PROPERTIES EXAMINED.

The Viati Mining Company, the Copper Basin prospects, and the deposits worked by Mr. Bowman are all located in the Monumental mining district of San Bernardino County, Cal., on the southeastern side of the Whipple Mountains, some 10 or 15 miles north of Parker, Ariz. A means of transportation for the ores is furnished by the Arizona and California Railroad, its nearest point being just across the river from Parker. At the time of the writer's visit to the district no large production had been reported from the various workings, although some ore was said to have been shipped from a prospect in Copper Basin.

VIATI MINING COMPANY'S PROPERTY.

GENERAL DESCRIPTION.

The properties worked by this company are situated near the head of Bennett Wash, 7 miles due north of Parker. The camp is located at an elevation of 1,350 feet, and a fair wagon road to the California side of the Arizona and California Railroad bridge over the Colorado, which is approximately 400 feet above sea level, is perhaps 3 miles longer than a straight line between the two places. Parker, Ariz., is the present base of supplies, although in the near future, with the completion of the Arizona and California Railroad, no doubt a town will be built on the west bank of the Colorado.

Timber is very scarce in the vicinity and has to be shipped in here, as to almost every other place in the area. Water for domestic use was being pumped from the mine at the time of the writer's visit to the property. Distillate is used in operating the machinery, and, according to a statement by the superintendent, costs 27 cents a gallon in tank lots delivered to the California side of the Colorado and 3 cents to freight it to the camp, a total of 30 cents a gallon at the mine. The best grade of distillate is used, and the consumption is given by Mr. Bennett as three-fourths of a gallon per hour on the 15-horsepower Fairbanks-Morse hoist. No shipments have been made from this property.

Equipment.—The principal equipment consists of a 15-horsepower hoist, a 9-horsepower vertical engine, a 7½-kilowatt dynamo, and an electric pump run by a motor.

Development.—The development work done on these claims consists of the Pasadena vertical shaft about 150 feet deep, from which 2 very short levels have been run separated from each other by a vertical distance of 75 feet, and of the Horseshoe Tunnel, a crosscut, approximately 80 feet long, southeast of which several rather shallow open cuts have been made upon quartz ledges which run north-st-southeast for some distance on the properties.

TOPOGRAPHY.

The deposits are located in a part of the Whipple Mountains, which marks the dividing line between the gradually sloping desert southeast and the high precipitous spurs of the mountains northwest. In the immediate vicinity of the deposits the ridges are steep but not very high, rising only about 200 feet above the washes. Farther northwest the acclivity is very much more pronounced, the ridges there attaining an altitude of several hundred feet above the bottom of the valleys.

GEOLOGY.

Gneisses and schists, presumably of pre-Cambrian age and probably resulting from the metamorphism of granites and basic diorites, form the hills in this vicinity. The schistose structure of all the rocks is very pronounced, and in general the lamination planes dip northeastward, although there are many local changes, and frequently the lines of foliation are almost flat. These rocks are presumably a part of the granite gneiss schist complex which has been so often referred to in the discussion of the Arizona ore deposits, and their mineral constituents are not dissimilar enough to warrant a separate petrographic description. Aplite dikes of large dimensions, locally called "white spar," are found throughout the gneisses. These are severely fractured, the small fissures in many places being completely filled with hematite, which by its slickensided surfaces shows postmineral movement. Near the outcrop of the quartz ledges which have been prospected on this property, the most prevalent rock is a metamorphosed diorite, the lamination planes of which are parallel to those of the granitic gneiss and which was intruded into the granite prior to its metamorphism.

ORE DEPOSITS.

Pasadena shaft.—The Pasadena shaft, at an elevation of 1,350 feet, which has been sunk to a vertical depth of 150 feet, was started with the intention of crosscutting to the west from the 200-foot level, and so, perhaps, cutting at this depth the possible continuation of quartz ledges, which outcrop on the surface some little distance away in the same direction. As only a small amount of mineralization is in evidence in the workings of the shaft the following description will deal mainly with the occurrence of the ledges as viewed along the surface outcrops.

On the 70-foot level a short crosscut has been driven northeastward, which intersects a small vein about 12 inches wide, occupying a fault plane in the granite gneiss and dipping 45° N. 65° E. Slickensided surfaces of the country rock are noticeable and gouge is present in large amounts. A thin stringer of copper glance 2 or 3 inches wide occurs in the vein, and pyrite, hematite, and quartz are also present. The ore is reported to contain, besides the copper values, a small amount of gold. Slickensided surfaces of the ore show post-mineral movement on a small scale.

At the bottom of the shaft, 150 feet from the collar, a crosscut has been driven northeast for a distance of 100 feet. Seventy-five feet along the crosscut a vein has been cut which dips 45° N. 65° E., and which is probably in a continuation of the fault plane found on the 70-foot level. On the 150-foot level, however, the fault zone is 4 feet wide and shows evidence of intense movement; slickensided surfaces are prominent and great quantities of gouge and brecciated gneiss form the vein. Here mineralization seems to be very scanty, no chalcocite being seen and only a small amount of pyrite with a very little chalcopyrite and some native copper scattered through the vein. In a small secondary fracture found cutting the fresh gneiss only a few feet beyond the vein, pyrite, hematite, and quartz are found.

This level has to be drained by a pump and may be under the ground-water level for the immediate vicinity.

Horseshoe tunnel.—The Horseshoe tunnel is located at an elevation of 1,400 feet about one-half mile above the Pasadena shaft in the wash which comes down to the camp of the Viati Mining Company from the northwest. The crosscut was driven to intersect two quartz ledges which show very prominently on the surface, one of which is probably encountered in the 80 feet of tunneling which constitutes the development in this working. This ledge is about 5 feet wide, strikes S. 25° E., and dips approximately 60° to 70° N. 65° E., here apparently cutting across the schistosity of the gneisses which at this particular place is very flat. Mineralization, except by the oxides of iron, is scanty, the silicate and carbonate of copper being very sparsely distributed. According to a statement made by Mr. Bennett of this company the ledge cut in this working carries some values in gold, the average being higher than on the outcrop.

Quartz ledge outcrops.—The outcrops of the ledges just above the crosscut are found at an elevation of 1,450 feet, and as there exposed vary from 5 to 8 feet in width and are separated from each other by 15 to 20 feet of gneiss. The croppings show a brecciated form of quartz which is heavily stained with the oxides of iron and a little manganese. The ledges contain many vugs, most of them filled with quartz crystals, associated with some calcite. Mr. Bennett is the authority for the statement that the croppings do not carry high values in gold. These croppings can be traced continuously for 1 mile in a southeasterly direction, the width varying between 1 and 8 feet.

On the way from the Horseshoe tunnel to the second opening on the croppings, which is about 3,000 feet southeast of the Horseshoe tunnel, gneiss was found to be continuous across the strike of the quartz ledges, apparently cutting them off. This is evidence in favor of the pre-Cambrian age of the quartz, showing that during regional dynamometamorphism the quartz veins were displaced and that in places their continuity was entirely cut off. Above the Horseshoe tunnel two ledges were in evidence. These continued parallel for some little distance, one of them not being present at the second opening, however, nor was it seen to the southeast of this opening. In places the ledge appeared to lie in the planes of schistosity of the gneiss and elsewhere to cut directly across them. A very basic schistose diorite or gabbro dike was noticed in the vicinity of the second open cut, which appeared to cut across the strike of the vein, although no contact between the two was visible.

Southeast of this opening the ledge appears to be faulted in a great many places and varies greatly in width, in general the croppings being narrower than those to the northwest.

Origin of the ores.—The exact nature of the origin of the deposits is rather doubtful. They are probably of pre-Cambrian age, and the quartz seems to have been introduced prior to the recrystallization of the granites and diorites into gneisses, evidence of this being found in the continuity of the gneiss across the main ledges whose outcrops are persistent in a northwest-southeast direction for over 1 mile. The partly brecciated condition of the quartz constituting the ledges is indicative of later movements in the vein or else of the introduction of the quartz just prior to the recrystallization of the granites. Very lean primary disseminated ores are sufficient to account for the mineralization in this region, which may have taken place during the dynamometamorphism of the area.

COPPER BASIN PROSPECTS.

GENERAL DESCRIPTION.

These properties are located just northwest of Monument Peak, about 15 miles by wagon road and 11 miles in an air line north of Parker. Not much development has taken place, nor has a permanent camp been built, and only small shipments of ore have been made from these prospects.[a]

TOPOGRAPHY.

After crossing a divide, which has an elevation of 1,450 feet, and is 2 miles southwest of the deposits, the road drops down into Copper Basin, which is in a small valley circling Monument Peak on the north and east and draining into a wash, which empties into the Colorado, a mile or so north of Eagle Landing. Monument Peak, which is just southeast of the prospects, rises abruptly to an elevation of 2,750 feet, and a small projecting finger on the southeast of the main peak is used as one of the corners in the Colorado River Indian Reservation.

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[a] Shipments are reported to have been made to Swansea, Wales, from Prospect No. 2.

GEOLOGY.

The deposits are in pre-Cambrian granite and granite gneiss which contain irregular dark patches, some of which are schistose and amphibolitic. In places there are small areas of distinctly gneissic rocks, aplites, and granitic rocks, surrounded by the massive granite. Monument Peak, to the southwest, is made up of lava flows, which are probably of basaltic composition. Plate III, *A*, shows Monument Peak in the distance.

ORE DEPOSITS.

Prospect No. 3.—This opening is the one nearest to Monument Peak and is a shallow shaft (80 feet deep) sunk on a fairly well-defined shear zone, 2 or 3 feet wide, which strikes N. 18° W. and dips 85° S. 70° W. . The country rock is imperfect schistose granite and diorite, one wall of which appears to be of diabasic origin. The gangue appears to be mainly an iron-stained gouge of brecciated country rock containing some oxidized copper ores with a little chalcopyrite and chalcocite.

Prospect No. 2.—About 1,000 feet north of No. 3 and separated from it by imperfect amphibolite schist, striking N. 70° E., with massive granite near by, is located Copper Basin prospect No. 2. Here a short adit has been run near the vein and a shallow shaft has been sunk. This deposit looks like an irregular chimney in hornblendic schist striking N. 35° E., the ore-bearing streak appearing to course N. 55° W. and to dip 75° N. 35° E. On the surface the vein appears to be about 3 feet wide and is all slightly mineralized by the oxides of iron and copper. Native copper, chalcocite, cuprite, malachite, hematite, and quartz are present in the vein, which is reported to carry some gold.

Summary.—These deposits are probably of pre-Cambrian age and are all contained in granite and schist, one of them being clearly connected with amphibolitic schist. They may be accounted for by the secondary concentration of very lean disseminated primary ores. No strongly defined fissures show in the workings, and there is probably little hope of extensive deposits.

BOWMAN PROSPECTS.

The deposits owned and worked by Messrs. Bowman Bros. & Humphries are located a short distance south of Monument Peak and a little east of the main Copper Basin road. Developments on the properties are in an early prospecting state, little work having been done. The two short adits and the open cuts show the contact between the old underlying massive granite, in which oxidized copper ores occur, and the capping of sandstone and tuff. The veins are small and look uncertain, with scanty mineralization, and only oxidized products were in evidence at the time of the writer's visit to the camp.

PROPERTIES ON THE ARIZONA SIDE OF THE COLORADO.

PROPERTIES EXAMINED.

Under this heading will be described the Quartz King, the Billy Mack, the Carnation, and the Wardwell & Osbourne properties, which are all located in the Williams Mountains in the northwestern part of the Santa Maria (or Bill Williams) mining district.[a] The first three properties are perhaps more properly classed in this group than in the last, for they are not far from Colorado River, whereas the Wardwell & Osbourne prospect is some distance southwest. Parker, on the Arizona and California Railroad, is the base of supplies, and is also the present shipping point for these properties.

QUARTZ KING PROPERTY.

GENERAL DESCRIPTION.

The Quartz King workings are located 5 miles northeast of Parker in an air line, and are made accessible by a good wagon road some 7 miles long between the two places. A store located on the main Colorado River road is kept up by the management, and telephone connections with Parker are maintained. There are several houses near the new workings on the property, and these with a shaft house constitute the surface improvements. The following machinery is installed in the shaft house: One 60-horsepower hoist, one 60-horsepower compressor, and one small blower. In the crosscut from the bottom of the new shaft one drill was in operation on May 1, 1909. Distillate is used for fuel, and about 50 gallons are reported to be consumed daily in operating the machinery. The property is being worked for gold and copper.

TOPOGRAPHY.

The deposits are located about 1½ miles from Colorado River and about 250 feet above it on the southwestern slope of a long narrow ridge which extends almost down to the river. The camp is located near the head of a small ravine at an elevation of 550 feet and about 150 feet below the older and upper workings on the property. The hills are not very precipitous and the peculiar topography in the vicinity is entirely dependent upon the geological relationships.

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[a] See figure 4 (p. 45) for map showing boundaries of mining districts.

GEOLOGY.

The rocks in the vicinity are amphibolitic and chloritic schists which are nearly vertical and strike northwest-southeast. Upon the eroded surface of these older rocks rest basalt and a clastic rock composed entirely of brecciated microline feldspar and quartz fragments. The ore deposit occurs in a shear zone or fault plane in the amphibolitic and chloritic schists, which resemble in a very general way the schists seen in the vicinity of Billy Mack's, Osbourne's, and many other places; it has probably resulted from the metamorphism of arenaceous shales intruded by diabase or other basic rocks. Joint planes are common in the clastic rock found resting on the amphibolite near the upper workings, and the basalt seems to be very platy and to have been jointed in a more or less local fashion. The irregularity of the contact between the underlying amphibolite and the later sediments and igneous flows forms the most noticeable feature in both the topography and the geology of the vicinity.

THE ORE DEPOSIT AS EXPOSED BY WORKINGS.

Upper workings.—The upper workings are located at an elevation of 700 feet. The vein, as observed at this place, appears to occupy a fault plane or a shear zone in the schists which strikes S. 20° to 30° E. in places and north-south in general. The dip is almost perpendicular, the inclination noted on the surface being to the southwest. Because of the nature of the deposit the gangue is principally sheared country rock which has been cemented in part by later deposition of quartz, showing brecciation due to subsequent movement. The ore minerals occurring with the quartz are malachite and chrysocolla with hematite. The deposit is not very extensive in width though quite persistent in length. The shaft here is reported to be 300 feet deep and to have 900 feet of laterals.

New shaft.—Some 300 feet below the upper workings a new vertical shaft has been started. This penetrates the clastic rock throughout the 100 feet in depth which had been attained at the time the property was visited. At this level a crosscut had at that time been driven toward the supposed continuation of the vein and had cut 70 feet of the same sort of clastic material.

BILLY MACK PROPERTY.

LOCATION AND DEVELOPMENT.

The property belonging to Mr. Mack which is commonly referred to as Billy Mack's Ruby mine is perhaps one of the best known deposits in the area. This is no doubt due to the fact that free gold occurs here in appreciable quantities and has in the past been mined in a way peculiar to the owner.

In an air line it is just 6 miles in a northeasterly direction from Parker to the Billy Mack adit on the Ruby property. By wagon road this distance is increased to 7 or 8 miles, and the difference in elevation between the two places is approximately 400 feet, the acclivity being mainly in the vicinity of the prospect. Little is known to the writer of the early history of this property. According to rumor the gold extracted from the vein has been the means of subsistence of its owner for a great many years, and it is said that the property has never been consistently worked. Surely the small amount of underground development testifies to the accuracy of this last statement. The production has been variously estimated, the highest estimate amounting to $65,000, and the tailings from a small 5-stamp mill are said to contain several thousand dollars' worth of gold which has not been extracted by stamping.

The work on the prospect has been done by hand drilling, and there is no machinery on the ground. The mill is located a short distance north of the Quartz King store and is just off the main Colorado River road, about 2 miles from the prospect. Water has not been encountered in any of the workings so far, the deepest of which are 165 feet below the level of the main opening. Some timber could be obtained in the locality along the banks of the Colorado.

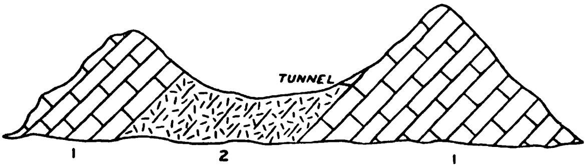


FIGURE 13.—Ideal section in the vicinity of Billy Mack property. 1, Limestone; 2, chloritic micaceous schist.

GEOLOGY.

The rocks in the immediate vicinity are limestones and chloritic schists, the latter being contained between conformable beds of the former, and the whole series strikes northeast and dips 45° NW. Figure 13 shows the geological relations existing in this locality.

The limestones rise on each side of the gulch to heights of 200 or 300 feet and are in rudely bedded benches, the weathered surface of which is dark brown. The texture of the fresh rock is fine grained and the color is a dark gray. Veinlets of siderite are found in abundance throughout the limestones. The ridge on the northwest probably represents a thickness of 200 feet. The width of the lower bench exceeds this dimension, but it is impossible to say by what amount, as the ridges northeast are composed of this material, and these may represent a thickness of between 200 and 700 feet, perhaps more.

The valley between these two horizons of limestone is about 800 feet wide, and has been excavated in soft chloritic micaceous schist, the thickness of which is probably not less than 500 feet. As seen in the creek bed the schist is slightly contorted and is of light greenish-gray color, containing small and likewise contorted quartz veins. This schist probably represents tuffaceous deposits or an old flow of diabase or related rock (perhaps the remnant of a quartz diorite or dacite) on top of the lower bench of limestone. Above this the sediments on the northwest were deposited. A thin section of the chlorite schist shows much talc and white mica, together with an abundance of chlorite, quartz, and a little feldspar. Amphiboles were probably present in the original rock, although none are now recognizable in the schist.

The whole series has been subjected to pressure, and, as the schistosity developed far more easily in the basic rock than in the limestones, the basic rock shows contortion, while the limestones are only crushed and brecciated in places.

ORE DEPOSIT.

As shown by the workings and the surface croppings of the vein, which are about 80 feet above the wash level, the deposit occupies the contact plane between the underlying limestone and the micaceous chlorite schist. Quartz is the prevalent vein material, and much of it is cellular, as if carbonates had been dissolved from it. A little amphibolite, epidote, and some chlorite were noted as associated with the deposit. The ore minerals are chiefly malachite and chrysocolla, with some native gold. Specularite, probably of secondary origin, is abundant in the workings. The deposit is not very regular, mineralization being in scattered bunches, with a noticeable lack of continuity between the various ore pockets. These in general have been only a few inches in width and not of great length, having been explored by individual workings.

The association of minerals found in this deposit is characteristic of copper deposits connected in origin with basic flows. Possibly the deposit was formed by concentration of the original metallic contents in the basic rock during the metamorphism of the region. The primary ore is probably poor in gold values.

CARNATION PROPERTY.

LOCATION AND DEVELOPMENT.

This property is located about 9 miles in an air line northeast of Parker, the wagon road between the two places being about 13 miles long. The camp, which consists of several tents, is situated at an elevation of 880 feet. The deposit is a very short distance to the east of the camp, and the workings are 100 and 200 feet higher on the west side of a bluff which has been eroded in such a manner that the remaining hills and ridges form a crescent-shaped background.

Water has to be hauled and is stored in tanks at the camp. The developments are in an early prospecting stage, and at the time of the writer's visit the property was idle.

GEOLOGY.

Massive limestones interbedded with amphibolitic and quartz-mica schists form prominent ridges on the north, and the same rocks are capped by tuff and nearly level olivine basalt flows on the east. The deposit occurs in the amphibolitic schists, and is prospected by a shallow inclined shaft just below the contact with the overlying basalt. In general the schists strike northeast-southwest and dip about 45° SE., although there are many local disturbances in the vicinity of the deposit and elsewhere, so that the directions of strike and dip are by no means constant. The presence of the medium-grained quartz-mica schist in this series is about the only thing which mars the similarity between this section and that at the Billy Mack locality.

The fractures in the basalt are filled with calcite, and no evidence of metallic mineralization exists in the younger rocks into which a short vertical shaft has been sunk.

ORE DEPOSITS.

The deposit here, as at the Quartz King, seems to occupy a shear zone or fault plane in the amphibolite schists. Ten or twelve feet above the vein occurs a thin layer of limestone, the top of which is partly replaced by hematite. Over this is a narrow band of medium-grained quartz-mica schist which is capped by tuff and a succession of basaltic flows. The vein, which is 2 or 3 feet wide, consists mainly of brecciated country gangue showing some mineralization by the silicate and carbonate of copper. Postmineral fracturing has occurred, followed by a recementing of material by siderite, calcite, and quartz, the latter forming jasper in places. Secondary specularite was noted in a specimen on the dump.

Origin of the ores.—It is possible but hardly probable that the quartz-mica schist may have been of igneous origin and intrusive in the limestone, thereby causing the mineralization. The more plausible supposition is that the ore deposit was formed by concentration of the original copper content of a basic flow or of tuffaceous rocks from which the amphibolite has resulted by the metamorphism of the region.

WARDWELL & OSBOURNE PROPERTY.

LOCATION AND DEVELOPMENT.

The property called by this name is situated some distance southeast of the rest of the Colorado River group, and is made accessible by a circuitous road from Parker, which is about 15 miles long and extends in a general easterly direction from that place. The prospect may also be reached by a branch from another road which is not so commonly used, the location of which can be seen by referring to Plate I.

As the property was idle and the workings were closed at the time of the writer's visit only a brief description of the ore occurrence as shown on the surface can be given. The principal underground developments consist of an adit tunnel located at an elevation of 950 feet and an inclined shaft, the collar of which is some 100 feet lower than the main adit. Besides these, three other small workings were noted, and, judged by the various dumps, the total developments are not very extensive. Probably no large shipments have been made from the property.

GEOLOGY.

In the vicinity of the Wardwell & Osbourne camp fine-grained quartz-mica and amphibolitic schists underlie tuff and olivine basalt, the younger rocks being barren of mineralization and covering for the most part the older rocks throughout this section. Erosion has cut through this series a short distance into the schists, which are exposed for about one-half mile farther west, where basalt again hides them from view. The uneven contact of the two formations is due to the irregularity of the old erosional surface which is now occupied by tuff associated with basalt flows. In general the schists dip southwest and strike northwest, the dip varying from 10° to 90°. Plate III, *A*, shows the basalt bowlders in the vicinity of the divide between Billy Mack's and the Wardwell & Osbourne property. Monument Peak is shown in the distance.

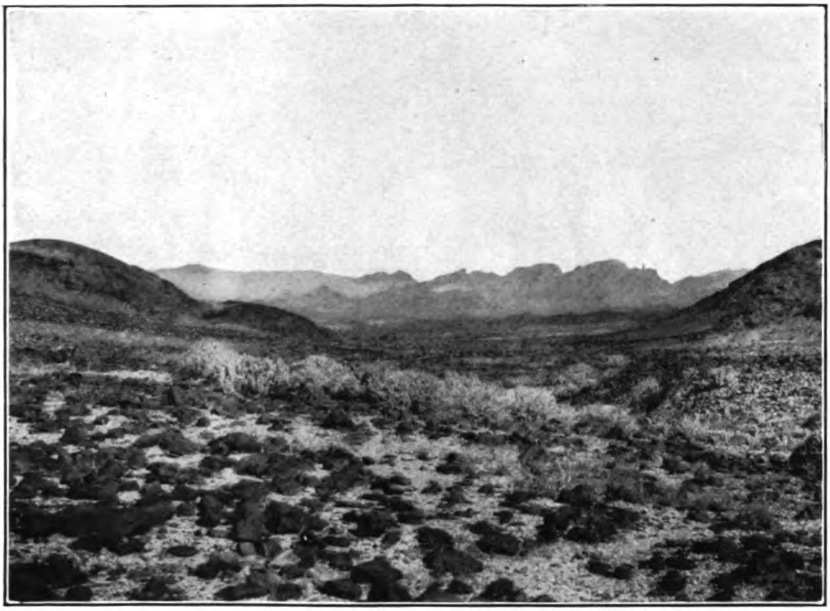
ORE DEPOSIT.

Judged by the surface exposures the mineralization seems to have taken place along a nearly vertical fault plane in the schists which strikes S. 30° W., and which is filled mainly with brecciated country rock cemented by siliceous material. The vein does not follow the planes of schistosity, but cuts directly across them. The shear zone is only a few feet in width and the ore-bearing streak, as viewed on the surface outcrop, is irregular and relatively narrow when present. A specimen of ore from one of the dumps shows a breccia of siliceous fragments cemented by hematite, with a little chrysocolla and malachite, the copper solutions apparently having been later than the others.

DEPOSITS IN THE DOME ROCK MOUNTAINS.

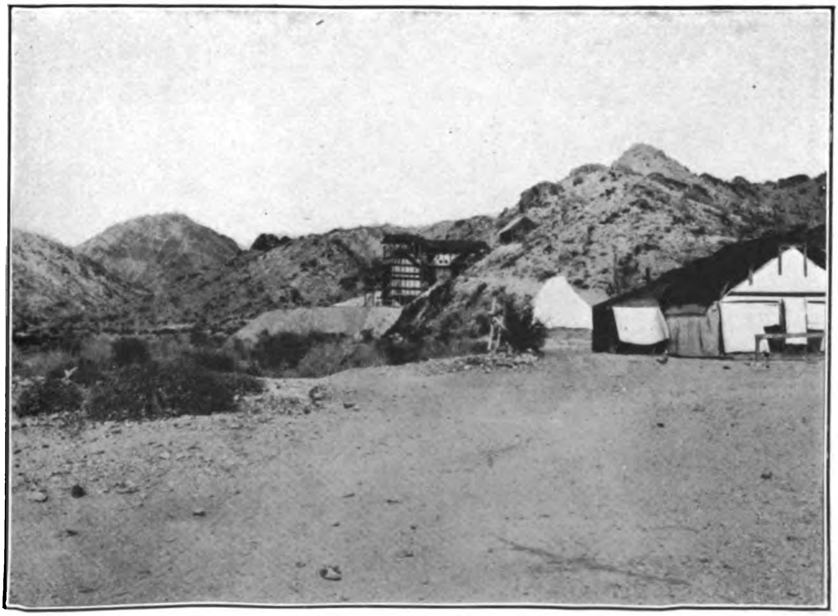
LOCATION AND CHARACTERISTICS.

The Dome Rock Mountains were among the first to be earnestly prospected for lodes because of the early discovery of gold placer deposits on their western slope. The results have not been as gratifying as anticipated; nevertheless, several veins carrying free gold ave been located. Because of lack of time the only free gold operty examined was the Mariquita.



A. BASALT BOWLDERS ON DIVIDE BETWEEN BILLY MACK'S AND WARDWELL & OSBOURNE PROPERTIES.

Monument Peak in the distance.



B. SMELTER AT CINNABAR, ARIZ.

Copper is also found in the range, the Valensuella deposit being the only one visited. Locally the Copper Bottom deposits seem to be well and favorably known, and the writer regrets that circumstances prohibited an examination of these prospects.

The Dome Rock Mountains have several individual characteristics, among which the occurrence of cinnabar in the southern part of the range is especially worthy of note. The deposit worked by the Colonial Mining Company was inspected, and a hurried visit was paid to the property of the French American Mining Company, a short distance west of Cinnabar.

With the exception of the Valensuella prospect all of the deposits examined in the Dome Rock Mountains are located in the southwestern part of the Plomosa mining district, the Valensuella probably being in the La Paz (or Weaver) district.[a]

Transportation facilities are not of the best for any of the properties in this vicinity. Bouse and Vicksburg, the nearest railroad points, are distant from Cinnabar in an air line 31 and 35 miles, respectively; and from the Valensuella camp, Bouse is distant 22 miles in a direct line. The wagon roads are necessarily longer, and transportation becomes a very expensive factor in the mining industry of the area. In the past some ore has been shipped down the Colorado.

VALENSUELLA COPPER COMPANY'S PROPERTY.

LOCATION AND DEVELOPMENT.

The deposit worked by the Valensuella Copper Company is located in the northern part of the Dome Rock Mountains near the Colorado River Indian Reservation line, the exact location of which seems to be an unsettled question. The location of the property on the reconnaissance map (Pl. I) is only approximate.

The nearest railroad point is at the town of Bouse, distant 22 miles in a direct line north of east of the camp; the distance by wagon road is not known to the writer. As no ore has been shipped from the property, costs of transportation can not be given.

Timber is lacking in the vicinity, and water is obtained from a well near the collar of the shaft, in which it stands 450 feet below the surface.

Equipment.—An 18-horsepower hoist and a 25-ton smelter, which has not seen much active service, constitute the company's principal equipment on the ground. The other surface improvements consist of several buildings and a smithy.

Underground development.—An inclined shaft the slope of which varies in dip from horizontal to 35° has been sunk to a total depth of 900 feet on the incline. From this shaft various short levels have been driven, making a total of about 1,600 feet of workings. The bottom of this shaft is probably 450 feet in a vertical distance below the surface, which is also the approximate ground-water level.

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[a] For boundaries of mining districts see figure 4, compiled by county clerk of Yuma County from official records.

TOPOGRAPHY.

The camp and workings are located in the northern part of the range at an elevation of 600 feet, and are at the base of a steep mountain slope just above the desert, which stretches away to the east for 12 miles or more. The drainage of the vicinity is into Tyson Wash, about 4 miles south of the Valensuella. On the west a narrow canyon with precipitous walls extends for three-fourths of a mile, and its course appears to have been determined by a fault. The canyon has nearly cut in two this northern projection of the Dome Rock Mountains, thereby revealing a good geologic section. The portion of the range as represented in this vicinity rises only about 500 feet above the desert, and is characterized by sharp peaks which terminate a narrow and uneven ridge.

GEOLOGY.

In the vicinity of the Valensuella camp the geologic section is unlike that seen in other localities which were examined during the reconnaissance of the area. The prevailing rocks are coarse-grained schists, and most of them appear to be metamorphosed sediments deposited from the erosion of granitic and dioritic rocks. One lens of cream-colored, coarse, crystalline limestone, about 12 feet thick, occurs in the schists in the section exposed south of the road and a short distance west of the camp. Limestone is reported to have been cut at a depth of 125 feet in workings on the north side of the road, about one-half mile west of camp.

The schists range in color from almost black to gray, pink, and silvery white, depending upon the kind and amount of mica present in the rocks. The very dark rocks carry much biotite and augite; the lighter ones contain more quartz, feldspar, and white mica. Intruded into the series, prior to their metamorphism, occur typical quartz porphyry and aplite, in which schistose structure is well developed. Later intrusives of pegmatite (garnetiferous), diabase (pyritiferous), and minette dikes are present in the vicinity. Of the first a great many were seen in the hills on the south side of the road. The diabase is fairly common in the vicinity; the minette seems rather scantily distributed, having been noted only in the workings of the prospect, where it occurs in the 100-foot level above the vein.

The schists in general dip northwest away from a gneissic micaceous granite found south of Tyson Wash, which granite is probably the oldest rock in the vicinity and is perhaps comparable to the granite gneiss complex of the Harcuvar Range.

ORE DEPOSIT.

The ore deposit occurs along a shear zone in the schists. The plane of movement varies from almost horizontal to a dip of 35° and has pinches and swells which tend to make a decidedly irregular deposit. In general, the strike of the vein is east-west and the dip is north. The vein varies greatly in width. In some places it is several feet wide; in others it pinches out. The ore course is even more capricious, occurring in irregular pockets and stringers and disappearing entirely between the 300-foot and the 400-foot level.

The gangue is composed of brecciated country rock, some quartz, and much calcite, the latter forming in bunches several inches in diameter throughout the upper 400 feet of workings.

Chrysocolla, some malachite, a little pyrite, and considerable hematite constitute the ore minerals.

As viewed at the 100-foot level, where drifts have been run 100 feet each side of the shaft and some stoping done, the parts of the vein exposed showed a little good ore. Most of the best material has been extracted, however, and little except the caved workings were visible. The ore is reported by the manager to contain 10 per cent copper and $1.50 in gold per ton. Above the vein occurs a minette dike.

On the 300-foot level drifts 200 feet in length have been driven on both sides of the shaft. These show scanty mineralization and not much continuity in the deposit. Between the 300-foot and the 400-foot levels the vein was lost. The manager of the property reports (May 6, 1910) that a crosscut back from the bottom of the shaft 150 feet has revealed a vein in place. The ores seem to be leached, however, and sulphides are not conspicuous.

Origin of ores.—At this deposit also oxidation veils the original character of the ore. The abundant calcite in the gangue suggests deposition nearer to the surface and perhaps at more recent time than in most of the mines previously described. The mineralization appears to be later than the development of schistosity, and it is possible that the ore deposition had some connection with the intrusions of diabase and minette noted in the vicinity

MARIQUITA PROSPECT.

The Mariquita prospect is located about 6 miles west of Quartzsite, the road leading to it branching from the Ehrenberg stage line some 4 miles out of Quartzsite. It is situated 2 miles north of the stage road at an elevation of 1,100 feet on the southeastern side of a saddle which occurs midway in the Dome Rock Mountains.

Medium to fine grained quartz-mica schists apparently intruded by much younger fine to medium-grained granites or quartz monzonites are the rocks in the immediate vicinity. The schists strike northwest-southeast and dip 20° NE., and they contain, besides the quartz and mica, much epidote and chlorite with a large percentage of orthoclase feldspar and some unaltered but contorted biotite crystals.

A fairly large vein of quartz carrying a little copper and gold, which has been roughly prospected, is the source of the ore extracted from this property. The vein strikes S. 20° E. and dips 20° NE., and lies in a slip or fault between parallel schist strata. In width the vein varies from a few inches to several feet, is fairly persistent in length, and apparently is lenticular. As the workings on the property are old and not very extensive, little accurate data on the size of the ore body were obtained.

COLONIAL MINING COMPANY'S PROPERTY.

LOCATION AND DEVELOPMENT.

The following sketch is simply a rearrangement of the material which was published by the writer in "Contributions to economic geology for 1909, part 1,"[a] under the heading "Notes on the occurrence of cinnabar in central western Arizona."

The property worked by this company has been known for a number of years[b] and is located at Cinnabar, which is in the southern part of the Dome Rock Mountains, some 8 miles due southwest of Quartzsite. Vicksburg, the most accessible railroad station, is in an air line just 28 miles a little north of west of Quartzsite. The stage road between the places is a few miles longer. The road between Quartzsite and the prospects is about 20 miles long and is a very poor one after branching off from the main Yuma road. Timber for use as fuel in the smelter and water for domestic purposes are obtained somewhere in the vicinity, although neither are found in great abundance.

The surface equipment consists of a good shaft house with adequate machinery for carrying on operations, several dwellings, and a 30-ton Scott tile furnace with six condensers. Plate III, *B* (p. 78), shows a view of the smelter and camp.

A vertical shaft 300 feet deep and four short levels running from it make a total of several hundred feet of underground development.

During parts of 1908 the furnace was operated on the property, a small quantity of mercury being recovered. High absorption of the metal by the bricks of local manufacture used in the condensers is reported by the management to have so lowered the percentage extracted that metallurgical operations have not proved profitable.

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[a] Bull. U. S. Geol. Survey No. 430, 1910, pp. 151-153.

[b] These deposits, according to Turner, have been known for over thirty years. See Turner, H. W., Quicksilver: Mineral Industry during 1908, p. 743.

TOPOGRAPHY.

The topography is characterized by broad sloping valleys with mountain ranges rising abruptly from the deserts. The Dome Rock Mountains have an average elevation of 1,500 feet, being approximately 1,000 feet above the surrounding country. The spur in which the cinnabar occurs forms the highest branch of the mountains, one of its peaks rising to an elevation of over 2,700 feet.

GEOLOGY.

The rocks in this locality are arenaceous shales, presumably of pre-Cambrian age, which have been metamorphosed into quartz-mica schists. The dip of the strata in the vicinity of the deposits is in general between 15° and 45° NE., and the strike is northwest, with many pronounced local changes in both. To the unaided eye most of the rocks appear to be fine grained, with a satiny sheen, ranging in color from light silver white through gray, brown, and red to a dark, almost black tone. The colors are due in general to the kind of mica and the amount of chlorite and epidote present, and in part to the degree of oxidation of the contained iron. Mica is prominent, and although the crystals are not large, they are conspicuous enough to be recognized without the use of a strong lens, and because of their abundance the rocks are fairly soft, feel greasy, and are readily scratched with a knife blade. Upon microscopic examination of thin sections it is found that the general composition of the schists is the same, all of them containing much quartz, orthoclase with some andesine feldspar, and mica, part of the latter probably resulting from the decomposition of the feldspars. Epidote is present in almost all of the schists, some of which are highly chloritized. Near the veins the wall rocks show calcite and epidote in abundance, with some zoisite.

The country rock in which the deposit worked by the Colonial Mining Company occurs is unlike the majority of the schists in the vicinity in that it contains scattered throughout the rock in large quantities small crystals of magnetite.

ORE DEPOSIT.

The vein worked by the Colonial Mining Company strikes S. 55° E., is practically perpendicular, and occupies a fault zone which shows intense brecciation of the country rock.

The gangue is highly siliceous and is cut by small stringers of calcite and siderite, the former occurring in places in conspicuous quantities but being entirely absent in the croppings of the vein where silica with a little black oxide of manganese forms the ledge. In width the vein varies from a few inches to several feet; parallel breccia planes of small magnitude, which accompany the main fault, in places tend to widen the deposit. The ore shoot in the property is said to pitch southeast.

Cinnabar is sparsely distributed throughout the gangue and is supposed to be found mainly on the northeast side of a very plastic, iron-stained gouge which has resulted from movement in the fault zone. The ore in places is conspicuously marked by the green carbonate of copper, and Turner [a] has reported gold and silver in ores from this deposit. The presence of magnetite near the vein is a feature worthy of note, the alteration of which has probably formed the red and yellow stains so common in the brecciated vein material and gouge.

Origin of the cinnabar.—Considering the facts that late eruptives are absent in the vicinity, that the deposit is entirely oxidized, and that copper stains are prominent, with values of gold and silver occurring in the vein, it seems highly probable that the cinnabar has been derived from mercurial tetrahedrite. Waldemar Lindgren has noted the occurrence of this mineral in gold quartz veins of the Granite district, Blue Mountains, Oregon, where pyrite, chalcopyrite, and arsenopyrite are also found.[b]

FRENCH AMERICAN PROSPECTS.

About 1½ miles west of the Colonial Mining Company's property up a steep and narrow gulch at an elevation of about 1,600 feet are located prospects owned by the French American Company. The present name is probably the result of a tradition that formerly the vicinity had been prospected and worked by Frenchmen.

A few open cuts show the character of the ledge and of the country rocks. The latter are mainly fine-grained quartz-mica schists with two prominent layers of impure limestone in the vicinity of the quartz ledge which is several feet thick and has a fairly continuous outcrop. There are found associated with the pure white quartz a noticeable amount of tourmaline, a little free gold, and some copper glance, all except the last apparently of primary origin. Siderite associated with gold and tourmaline was noted, and cinnabar is said to occur with the tourmaline in the quartz, although none was in evidence at the time of the writer's visit to the property. The vein strikes N. 55° W. and dips about 15° SE., cutting directly across the schists, which have a dip of 20° to 30° N. 60° E. A variety of schist next to the vein is highly impregnated with tourmaline, while another schist in the vicinity is extremely silicified.

The association in this vein of primary quartz, tourmaline, and gold is thought to indicate deposition under rather high temperature and pressure.

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[a] Turner, H. W., Quicksilver: Mineral Industry during 1908, p. 743.

[b] Twenty-second Ann. Rept. U. S. Geol. Survey, 1901, p. 663.

PLACER DEPOSITS NEAR THE DOME ROCK MOUNTAINS.

LOCATION AND HISTORY.

The placer deposits near the Dome Rock Mountains were among the earliest discoveries in central western Arizona, and they have been worked with more or less success in an intermittent fashion ever since 1862. As no work was in progress at the time of the writer's visit and as it was impossible to examine the famous La Paz district, it has been thought advisable to incorporate in this description extracts from the report of J. Ross Browne on the mineral resources of the States and Territories west of the Rocky Mountains, published in 1868. Mr. A. McKey, one time member of the Territorial legislature from La Paz, is the authority for the following information on the La Paz district:

Captain Pauline Weaver and others, in the month of January, 1862, were trapping on the Colorado River, and at times would stray off into the mountains for the purpose of prospecting for gold. They had discovered what was then named and is still called "El Arroyo de la Tenaja," which is about 2 miles north from El Campo Ferrá, and about 7 miles east from La Paz. In this gulch they had discovered gold in small quantities and had taken out $2 or $3 worth, which Captain Weaver kept in a goose quill.

Soon after this discovery Weaver visited Fort Yuma and exhibited what gold he had. This evidence of the existence of a commodity so much sought for in this country convinced others that gold might be found in quantities by hunting for it. Don José M. Redondo, having heard of the discovery, at once set out to visit the newly found "El Dorado" in company with several others. He arrived a few days afterwards at the camp of Captain Weaver, who pointed out to him and his party the particular gulch from which he had taken the gold. After a short examination of this place the party set out in different directions to discover, if possible, something which would pay to work, and the extent of the placers. Within less than a mile from Weaver's camp, south, Redondo took a pan of dirt to prospect, and when he had dry washed it, to the astonishment of himself and the party with him, he found that he had one "chispa," which weighed 2 ounces and $1, besides other small pieces. Others of his party found good prospects, but none of the company had come for anything more than to ascertain the truth or falsity of the reported glad tidings, and therefore were not prepared to remain and work for want of the necessary provisions and tools, but were compelled to return to La Laguna, a settlement some 20 miles above Fort Yuma, on the Arizona side of the Colorado. * * * Very soon the knowledge of these discoveries spread to Sonora and California, and people began to pour in from all points, and continued to come until they probably numbered 1,500. This population was maintained to a greater or less extent until the spring of 1864, when the apparent exhaustion of the placers and the extreme high prices for provisions caused large numbers to leave. The discovery of the Weaver and Walker's diggings in the year 1863 drew away many of the miners from these placers.

Of the yield of these placers, anything like an approximation to the average daily amount of what was taken out per man would only be guesswork. Hundreds of dollars per day to the man was common, and now and again a thousand or more per day. Don Juan Ferrá took one nugget from his claim which weighed 47 ounces and $6. Another party found a "chispa" weighing 27 ounces, and another one of 26 ounces.

Many others found pieces of from one to two ounces up to 20, and yet it is contended that the greater proportion of the larger nuggets were never shown for fear of some evil spirits who infested the mines at the time. It is the opinion of those most conversant with the first working of these placers that much the greater proportion of the gold taken out was in nuggets weighing from $1 up to the size of the "chispas" above named. I have often heard it said of those days that "not even a Papago Indian would work for less than $10 per day."

As has been seen from the above, the gold was large and generally clear of foreign substances. The largest piece (above mentioned) did not contain an apparent atom of quartz or any other base matter. The gold from the different camps varied a trifle in its worth at the mint in San Francisco, and brought from $17.50 to $19.50 per ounce. But all that was sold or taken here went for from $16 to $17 per ounce. Since the year 1864 until the present there have been at various times many men at work in these placers, numbering hundreds in the winter months, but in the summer months not exceeding 75 or 100; and all seem to do sufficiently well not to be willing to work for the wages of the country, which are and have been for some time from $30 to $65 per month and found. No inconsiderable amount of gold comes in from these placers now weekly, and only a few days ago I saw, myself, a nugget which weighed $40, clear and pure from any foreign substance.

Some parties have lately come into these diggings with what is called concentrators or dry washers, which they have been working for a few weeks, and in conversation with Mr. Finkler (an owner of one of these machines) he told me that he could make $20 per day where he was at work, and pay $3 per day for his hands, and that he only required four to work the machines. Should these machines prove a success, these placers will soon be peopled again with industrious, prosperous miners. Of the total amount of gold taken from these mines, I am as much at a loss to say what it has been as I was to name the average daily wages of the first years, and as I might greatly differ from those who were among the first in these mines, I do not feel justified in setting up an opinion as against them; I shall, therefore, give the substance of the several opinions which I have obtained from those who were the pioneers of these placers. I have failed to find any one of them whose opinion is that less than $1,000,000 were taken from these diggings within the first year, and in all probability as much was taken out within the following years.

In the desert which extends between the Dome Rock and the Plomosa mountains and is traversed by Tyson Wash, placer mining by dry washing has been carried on intermittently for a great many years. Innumerable short shafts have been sunk in the detrital deposits, and these openings are in many instances connected by underground tunnels. At the present time placer mining is not receiving much attention in this district, and, as the dry washers save only the large flakes of gold, water is an essential feature in thoroughly prospecting these deposits.

ORIGIN OF THE PLACERS.

When the age of the rocks and the ore deposits contained therein is considered in conjunction with the tremendous amount of erosion which has taken place in the area and the omnipresence of minute auriferous quartz gash veins, it does not seem unreasonable to suppose that the placers owe their origin to the veins located in the adjacent mountains.

DEPOSITS IN THE PLOMOSA MOUNTAINS.

LOCATION AND PROPERTIES.

Among the prospects examined in the Plomosa Mountains, which properties are in the southwestern part of the area and extend north to the Arizona and California Railroad, are included deposits of gold (placer), lead, copper, and iron. Vicksburg is the nearest railroad point for the New York-Plomosa and the Guadalupe, and Bouse is the most convenient station for the Lead Camp, the Mudersbach, the Iron Mine, and the Little Butte properties. All of the properties are located in the Plomosa mining district,[a] and are near the base of the range just above the contact with the surrounding desert. Only one of the properties, namely, the Little Butte, was actively operated at the time of the visit to the district; hence the information obtained on these deposits was principally of a geological nature. The writer regrets that circumstances prevented him from visiting the Success property, located about 3 miles south of the Guadalupe. Two carloads of ore shipped from this deposit are reported to have netted $105 each, and a third to have returned a slightly smaller amount, the values being in gold and copper.

NEW YORK–PLOMOSA.

LOCATION AND DEVELOPMENT.

Various placer deposits in the area have been worked intermittently for a number of years, but none of them, so far as the writer is aware, have been prospected on a large scale, nor have they been attacked in a manner similar to that employed by the New York-Plomosa Company, dry washing having been the usual method of procedure. This company, however, in the last few years has installed large machinery, laid a 7-mile water pipe line without any expansion joints, and has got all ready to work the placers. For some reason only one run had been made prior to May, 1909, the results of which were not available.

The deposits worked by this company are located near the southwestern end of the Plomosa Mountains in the western slope and are, in an air line, 24 miles a little south of west of Vicksburg. By wagon road, however, the distance is increased considerably, the property usually being approached from Quartzsite.

There has been installed on the property the following machinery: Three 100-horsepower boilers, one 300-horsepower Corliss engine, two Williams mills, two Huntington mills, and various accessories. The pipe line which furnishes the water used on the property is approximately

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[a] For location of mining districts see figure 4 (p. 45), compiled from official records by county clerk, Yuma County, Ariz.

7 miles long and is about 5 inches in diameter, the difference in elevation between the two terminals of the line being approximately 400 feet.

The ground has been prospected by a great many small tunnels with frequent openings to the surface, and an occasional larger adit tunnel run along the bed rock. The vicinity had previously been prospected by "dry washers," and consequently the underground work resembles a network of small burrowings, some of which a man can scarcely drag himself through. An accurate idea of the explored territory could not be obtained, as many of the workings were inaccessible.

GEOLOGY.

The bedrock in the vicinity of the deposits is a grayish-green partially schistose rock composed essentially of quartz and andesine feldspar, with some epidote and noticeable amounts of chlorite; the texture is fine grained and weathered surfaces show an imperfect schistose structure. Overlying this bedrock in places is a dark-colored greenish rock which is locally decidedly schistose; it is composed of quartz, andesine, or labradorite feldspar, and hypersthene, with a large amount of white mica and chlorite, and is presumably of igneous origin. This rock is exposed on the surface of the foothills east of the workings, where the lamination planes dip west and northwest at a comparatively flat angle. Quartz veins of small magnitude occur in both of these formations. A ridge of medium to coarse-grained quartz-biotite schist was observed a short distance northeast of the property, and a mile away in the same direction a coarse-grained gneissic rock was seen. This last type also contains quartz lenses and is cut by aplite dikes, which were not observed in the immediate vicinity of the New York-Plomosa.

ORE DEPOSITS.

In certain old drainage channels which led away from the southwestern part of the Plomosa Mountains is found an auriferous conglomerate of granite, schist, and quartz fragments cemented by lime carbonate. In thickness this conglomerate or "cement rock" varies from a few inches to a great many feet, the depth depending largely on the shape and size of the formerly existing channels. It is certain that placer gold occurs in this cement rock, but no data of the average tenor or the probable cost of working could be obtained. It was evidently the intention of the company to work the cemented material in mills. The quartz veins in the mountains close at hand are thought to be a reasonable source of origin for the gold found in the placers.

GUADALUPE (MORENO).

The Guadalupe prospect is located at an elevation of 1,800 feet on the western side of the southern part of the Plomosa Mountains, and is just west of the divide over which is built the stage road between Quartzsite and Vicksburg, which places are respectively 11 and 21 miles by wagon road from the Guadalupe. As the property was not worked at the time of the writer's visit only a superficial examination was possible, the underground developments being inaccessible. Apparently the deposit has been prospected by a short vertical shaft in addition to several surface cuts. Abandoned buildings and a shaft house constitute the surface improvements. Small shipments are reported[a] to have been made to San Francisco and to the smelter at Needles, Cal.

Geology.—As one approaches the Guadalupe from Quartzsite all of the rocks forming the cliffs are of volcanic origin up to within a short distance of the property. On the west these are mainly hornblende andesites and are probably of Tertiary age. In the immediate vicinity of the prospect south of the road are found more ancient rocks, probably of pre-Cambrian age. The basal member appears to be a coarse-grained silicified sandstone or arkose, and although it is impossible to state positively whether the rock is of sedimentary or igneous origin, evidence seems to favor the view that it is a recrystallized quartzose sediment, and it is in this formation that the Guadalupe vein outcrops. Lying on top of this is found a slightly schistose basic rock which appears to be of dioritic origin and which apparently represents an old flow upon the surface of the underlying quartzose rock.

Over these a few hundred feet north lies a limestone conglomerate of variable thickness, above which come about 300 feet of bluish, reddish, and yellowish limestone of unknown age. These dip about 10° SE. and strike N. 60° E., and form a prominent peak which is capped by olivine basalt.

On the south the andesites probably cover the older rocks and these are no doubt also capped by basalt.

Ore deposit.—As shown by the surface cuts the deposit is in the form of a true fissure vein cutting the quartzitic rock. The trend of the ledge is S. 25° E. and it stands almost perpendicularly. The width varies from a few inches to several feet, the ledge seeming to be quite persistent along its outcrop. Numerous stringers of the main vein were noted which did not show marked continuity or definition, and these dipped at all angles. The filling of the vein consists almost wholly of pure white quartz in which occur many veinlets of siderite, said[a] to be auriferous, which mineral is also prominent in the fractures and joints of the quartzose rock. Galena, reported[a] to be argentiferous and very slightly auriferous, was found in places in the vein, inclosing quartz, and from the ore dump good-sized specimens of this lead sulphide were examined. The carbonate and sulphate of lead were seen on some of the specimens, and a small amount of malachite was observed. Some hematite is present in the ore. The writer regrets his inability to give details of the continuation of the vein in depth.

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[a] Personal communication from Mr. W. J. Stoneham.

LEAD CAMP.

This property is about 9 miles almost due south of Bouse, and is in the northern part of the Plomosa Range, 1 mile northeast of Ibex Mountain, at an elevation of 1,400 feet, being somewhat higher than the town of Bouse, with which place it is connected by a fair wagon road. The property has not been productive recently, the last shipment having been made several years ago. This is reported to have been of 3,700 pounds, which carried $10 in gold to the ton and 45 per cent lead, mainly in the form of the carbonate. The developments on the property are only of a prospecting nature, and consist mainly of superficial exploration with open cuts and a shallow shaft.

The rock in which the vein occurs resembles a silicified rhyolite which has the appearance of antedating the Tertiary lavas found in other parts of the area, and is composed of the main constituents—silica and feldspar. This rock is reddish or pinkish in color and felsitic in texture, the altered feldspars being the only distinct phenocrysts visible, and it is possibly a recrystallized sediment. Intruded into the siliceous formation are diabase dikes of uncertain relation to the ore body, it being impossible to determine whether they cut the vein or not. West of the camp limestone caps the older basal gneiss formations and is probably older than the rock which resembles a rhyolite. The limestone apparently is continuous with that seen in the vicinity of the Iron Mine, and perhaps is persistent throughout the lower part of the Plomosa Mountains. The limestone noted on the north of the road between the Guadalupe and Vicksburg might well be a part of the same formation. Just west of camp the limestone seems to be intimately associated with a white, fine-grained quartz-feldspar rock, and the general appearance of the two points to the conclusion that the limestone has been intruded by this rock. Microscopic study of thin sections shows that the rock in all probability is of clastic origin and has resulted from the erosion of a granite, contemporaneous deposition of this material and of limestone having probably taken place. A short distance southwest of the old workings the vein cuts across the limestone, and elsewhere is in the silicified type of rock.

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[a] Personal communication from Mr. W. J. Stoneham.

The deposit seems to be a true fissure vein and, as exposed on the surface near the lower opening, strikes N. 80° E., and stands almost vertically. It is about 12 inches wide and is filled with a gangue of quartz, which is slightly mineralized by chrysocolla, malachite, and iron oxides. A short distance away in the upper workings and in a shallow shaft a vein apparently strikes S. 15° E. and dips a little northeast, standing almost perpendicularly. Farther southwest galena is found along the outcrop of the vein.

MUDERSBACH COPPER CAMP.

The deposits of the Mudersbach copper camp differ from all previously described in this paper in that they represent true contact metamorphic deposits formed at the contact of an intrusive cooling magma. The other deposits examined in this area which show strong evidence of contact metamorphism are the Cobralla, the Yuma Copper Company (I. & A.), and the Calcite.

The Mudersbach copper prospect is located 2 miles northwest of the Lead Camp at an elevation of 1,400 feet, and is just 8 miles in an air line a little west of south of Bouse. The road between the railroad station and the copper prospect is only moderately good, being sandy in places with some steep grades in the vicinity of the camp. The development work done on the prospect is small, consisting of a few surface cuts with two shallow shafts. One carload of ore has been shipped, which the owner reports averaged 10.4 per cent copper and $1 in gold per ton.

GEOLOGY AND ORE DEPOSIT.

The northern part of the Plomosa Mountains slopes gradually down to the level of the desert, and the rocks which form this portion of the range appear to be for the most part granites and schists with some limestones, all of probable pre-Cambrian age. These formations have been cut by later intrusives at different periods, one type of which is especially interesting in connection with the Mudersbach copper property. The oldest rocks were observed a short distance north of the property and consist of schists and partially schistose granite, the latter being similar in general appearance to the granite found in the Little Butte vicinity. These older rocks are cut by dikes of aplite and diabase, which intrusives are seldom absent in the pre-Cambrian granite gneiss schist complex of this area. On top of this series is found a thin band of fine-grained white quartzite and then about 100 feet of variously colored crystalline limestones, brown predominating, but yellow and blue noticeable. These limestones are metamorphosed to some extent, and show local silicification and some fracturing with calcite filling the fissures. One stratum of gypsum was noted which was several feet wide and several hundred feet long. This gypsum has probably resulted from the alteration of limestone in place, the alteration being carried on by the sulphuric acid liberated in the oxidation of pyrite, which is found in all stages of decomposition in the deposit. The limestones dip south in general, although with no regularity, other directions being prominent. A light-colored, medium-grained quartz monzonite porphyry has intruded the series, and judging from the exposures has stopped near the base of the sediments. Phenocrysts of biotite are prominent, and in thin sections micropegmatitic structure is plainly visible in the quartz and feldspar crystals. In general the limestones do not show much alteration, but at their base near the contact with the quartzite and the intruded magma a narrow band of garnet, associated with specularite, calcite, and other contact metamorphic minerals, has been formed.

Here also occurs the ore deposit, apparently replacing to a limited extent the limestone and a thin conglomerate at its base. The replacement has been in an irregular, pockety manner, as is shown in the outcrop and in the surface cuts, and the amount of replacement varies from a few inches to several feet. The ore is principally hematite with some copper in the form of carbonates. A specimen taken from the dump, however, shows primary pyrite, chalcopyrite, and specularite in a gangue of quartz and calcite with a secondary chlorite mineral. A coating of bornite is present on some of the sulphide crystals, and secondary iron oxides are also conspicuous.

IRON MINE.

This property is located 6 miles in a direct line southwest of Bouse at an elevation of 1,150 feet and is in the extreme northern part of the main mass of the Plomosa Mountains. Small surface cuts constitute the development work done on the property, which has not been operated for some time. No production from this place is reported.

The rocks in the vicinity are limestones, presumably pre-Cambrian, which have been rather severely cut up by eruptions of probable Tertiary acidic lavas. The limestones rest on normal biotite granite and where observed vary in dip from 50° S. 40° W. to almost vertical. Tuffs containing jasper and a rather thick conglomerate form noticeable geologic features a short distance north of the property.

The limestones are partly replaced locally by hematite in an irregular fashion, these beds still retaining their sedimentary characteristics, and the replaced strata in places being separated by beds of barren limestone. The hematite is very impure, containing much calcareous and siliceous material. The width of continuous replacement of the limestone by hematite ranges up to several feet. Siderite is present in notable quantities.

LITTLE BUTTE AND VICINITY.

LOCATION AND DEVELOPMENT.

This locality takes its name from a topographic feature in the vicinity, a small butte one-fourth mile from the shaft, which forms the extreme northern part of the Plomosa Mountains. The Little Butte prospect is situated 4 miles northwest of Bouse and approximately 1 mile south of the railroad, where the lowest foothills of the range merge into the gravel plain sloping down to Parker. The property has been prospected by different owners and several shipments have been made. At the time of the writer's visit, although a good camp had been established, developments were just being started, the incline shaft was only down a short distance,[a] and only a small amount of machinery had been installed on the property.

GEOLOGY.

The area just west of Little Butte, including the small hill known by the same name, is composed mainly of a medium-grained crumbling granite which shows slight schistosity and whose principal mineral constituents are biotite, orthoclase feldspar, and quartz. The rock is not very fresh; the feldspars show kaolinization, and the whole is stained a reddish-pink by iron oxides. Small irregular masses and veins of quartz and pegmatite are found in this granite, which is also intruded by dikes of diabase which take all kinds of forms and shapes. The diabase is schistose in places and is evidently a later instrusion than the pegmatites, these being cut by it.

At the Little Butte property an area of sedimentary, probably pre-Cambrian, rocks begins. These take the form of a broad crescent striking east-west and dipping about 20° S. The basal member of the series is a rough brown limestone, which is similar in many respects to that noted in various other parts of the area. Here, however, the rock is more shaly, and a large part of it consists of dark-gray and dark-green lime shale. This type of rock is continuous for about 1,000 feet southwest of the shaft, where the limestone borders against granite and is evidently on top of it. Near the Little Butte shaft the outcrops of the limestone show partial and complete replacement by specularite carrying in places some copper oxide ores. Granite prevails for three-fourths mile farther southwest where there is a prominent ridge of very cherty brown to yellowish-brown limestone. Here the sediments strike N. 54° W. and dip 30° SW., and these continue to the northwest, forming a low ridge in which are located the Blue Slate prospect and others. This belt of brown limestone is probably not over 1,500 feet wide and is overlain on the south by rough hills of a partly brecciated flow rock which possibly represents an old rhyolite and occupies a strip of country at least 1 mile wide.

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[a] The incline shaft is now (March, 1910) reported to be down 385 feet.

ORE DEPOSITS.

There are at least two kinds of deposits in this vicinity—those in the sedimentary area and those in granite. The latter type is represented by a considerable number of steep northeast trending quartz veins which are often irregular and frequently faulted, and some of which are reported to carry gold values in appreciable quantities. A shipment is said to have been made from the Sunshine lode which brought very good returns. These quartz veins probably represent an epoch of vein formation earlier than the sedimentary series.

The Little Butte and the Blue Slate are representatives of later deposits in the sedimentary series, and these typify two distinct classes of mineralization. The Blue Slate is a fissure striking N. 60° W. and standing nearly vertically in dark-green flat-lying shales. The gangue is crushed shale; specularite and oxidized copper ores are present; and thin films of gold occur in places as a coating to the lime shale. This occurrence of gold is similar to that noted in the Moro prospect of the Clara Consolidated Company.

The Little Butte deposit represents a partial replacement of limestone by hematite, with which is associated a little oxidized copper ore and a secondary concentration of these oxides along the contact of the granite and overlying limestone. As viewed in the underground workings exposed in March, 1909 (all above the 200-foot level), the ore occurred in irregular lenticular bunches just below the contact with the overlying rock. These shoots were not very persistent and showed more in the nature of pockets than otherwise. The general strike of the contact of the two formations as exposed underground is S. 18° E., and the dip varies from 30° to 40° E. R. P. Sharpe, the superintendent of the Little Butte Consolidated Mines Company, reports [a] that the inclined shaft is down to a depth of 385 feet and that the amount of water coming in has been so great that developments below the 300-foot level have been suspended pending the arrival of heavier pumping machinery. He says that from the point where water was first encountered at 210 feet depth, the granite foot wall became highly leached and correspondingly soft, and that rich bunches of oxidized copper ores were encountered at a depth of 350 feet on the incline in the granite some 25 or 30 feet away from the contact. These ores are said to carry good values in gold, as also are those developed on the 200-foot and 300-foot levels, where copper ores are practically absent. From the 200-foot level to the surface 22 cars of ore were stoped and shipped. These, Mr. Sharpe reports, averaged 7.6 per cent copper, 28.9 per cent iron, 32.4 per cent insoluble, with 2.4 ounces of silver and $6.65 in gold to the ton. Sulphides had not been found in the workings up to the date of Mr. Sharpe's letter, March 6, 1910. Gold is reported to occur also in the hanging wall and is said to be found at distances of 20 to 30 feet away from the contact.

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[a] Personal communication by letter under date March 6, 1910.

Specularite and quartz with a little chlorite were the principal gangue minerals noted. The ores show an intimate association of specularite, chrysocolla, and malachite, the last occurring in radial bunches scattered throughout the chrysocolla, with quartz crystals lining some of the open spaces in the ore. Thin sections of the ores show a breccia of chrysocolla and malachite, cemented by specularite. One thin section of a piece of rock taken from an outcrop of limestone about 800 feet south of the Little Butte shaft shows in banded structure the apparent contemporaneous deposition of primary specularite, quartz, and calcite or dolomite. A stratum of rock in this same locality shows beside the replacement of the limestone by hematite, small fissures in the rock filled by hematite, the mineralization appearing to have taken place at one period. The carbonate rock presents a highly chloritized appearance, but it is thought that the color is due principally to staining by iron oxides.

DEPOSITS AT THE SOUTHWEST END OF HARCUVAR RANGE.

GENERAL DESCRIPTION.

The southwestern extension of the Harcuvar Range contains some interesting free-gold prospects and a few copper prospects. Among the former type may be mentioned the Yellow Bird and the Arizona Northern, the last being locally famous in 1909 as the "Salome Strike." The I. & A., or Yuma Copper Company, and the Calcite are both being prospected for possible copper deposits. There were also a number of prospects which the writer desired to visit, but which had to be neglected because of limited time. Among these should be mentioned the Ultimatum of the Tank Pass Consolidated Mining Company.

All of these deposits are located in the Ellsworth mining district,[a] which district is sometimes known as the Harcuvar, and they are, with the exception of the Arizona Northern, situated near the base of the mountain range, being easily accessible by wagon roads. Vicksburg is the most convenient railroad point for all except the Calcite and the Cobralla, Salome being the natural station for these properties.

YUMA COPPER PROPERTY (FORMERLY I. & A.).

LOCATION AND DEVELOPMENT.

The property of the Yuma Copper Company is 7 miles due north of Vicksburg and has been prospected by shallow surface cuts and short shafts, the deepest of which was inaccessible when the property was visited.[a] At that time a new inclined shaft was being sunk a short distance northeast of the so-called iron dike which is a prominent feature in the vicinity of the camp. Water is obtained from a well on the property.

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[a] See figure 4 (p. 45) for map of mining districts prepared from official records by the clerk of Yuma County.

GEOLOGY.

In the immediate vicinity of the various prospects there is a marked similarity in the general geologic section, although there is a distinct difference in the type of rock found at each of the three workings visited. Just east of the camp a steep mountain rises to an altitude of 3,200 feet, which is 1,400 feet above the camp of the Yuma Copper Company. The geologic section exposed here is composed almost entirely of rocks belonging in the general series of pre-Cambrian metamorphosed sediments which are found throughout the southwestern part of the Harcuvar Range and elsewhere in the vicinity. These are medium to fine-grained quartz-mica schists and arenaceous shales, intruded in an irregular manner by acidic and basic dikes which usually follow but occasionally cut directly across the planes of schistosity. Some of these are vogesite dikes presumably connected with the intrusion of the granite which forms Salome Peak only 1½ miles northeast of this mountain, and the rest are comparable to those already described as present in the sedimentary schist series. A thin band of rock, composed entirely of epidote, augite, hornblende, and albite, their relative abundance being in the order named, was observed near the base of the steep rise. This rock probably represents the result of contact metamorphism, which has accompanied the intrusion of the granite, the main mass of which is only a short distance northeast and branches of which are present in almost every part of the southwestern end of the Harcuvar Range. Small stringers of quartz occur throughout the section, and in many instances occupy joint planes in the rocks.

The partial replacement of a ledge of yellow crystalline limestone by magnetite in the vicinity of the camp is the most conspicuous part of the section exposed on the property. This replacement, though not entirely regular, is several feet thick and of considerable length. Thin layers of actinolite are present in the magnetite and quartz is also fairly conspicuous, all three constituents, as shown in a thin section, appearing to have crystallized contemporaneously. Calcite is also a prominent component of the ledge. The replacement of the limestone by magnetite may be one of the results of the metamorphic action produced by the intrusion of the granite in this general vicinity.

The new inclined shaft which was being sunk a short distance northeast of this magnetite ledge had for walls a very highly chloritized and epidotized, fine-grained schist, which showed some copper and manganese oxide stains in the joints and lamination planes and was underlain by a very impure limestone in which occur many pseudomorphs of hematite after pyrite and numerous vugs lined with calcite.

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[a] In a report issued by the company, March 16, 1910, the total development up to January 1, 1910, is claimed to be 1,022 feet, of which 543 feet is in shaft sinking and the rest in drifts, crosscuts, and surface trenching.

The dump of the vertical shaft showed two distinct types of rock—one a very much metamorphosed, fine-grained quartz-mica schist highly chloritized and carrying noticeable quantities of pyrite, and the other pure white gypsum. The schist was fractured and the crevices filled with calcium sulphate, the latter occurring in such quantities on the dump as to indicate large deposits of this material below. As the shaft workings were inaccessible, nothing can be said about them.

The dump showed no promising looking ore, and the rocks thereon have been described.

YELLOW BIRD AND VICINITY.

GENERAL DESCRIPTION.

This is one of the interesting free-gold localities in the area which has been intermittently prospected for a number of years. It is situated just 5 miles north of Vicksburg. There are no extensive developments in the vicinity, and it is now interesting mainly to the geologist and mineralogist.

GEOLOGY.

The prevailing rocks are fine-grained slates and quartz-mica schists, with thin layers of intercalated limestone. In general the schists south of the Yellow Bird camp dip 10° to 40° SE., although locally they are severely contorted and folded and in places show evidence of faulting. The slates are grayish blue in color, are very fine grained, and appear to be metamorphosed calcareous shales traversed by minute stringers of calcite. The schists are in general similar to those already described in other localities where quartz-mica schists are prominent. Here they are fine grained, have a dull satiny luster, and are composed essentially of quartz and white mica. Chlorite and iron oxide have so stained the rocks that various colors have resulted. Diabase intrusives are common in the vicinity, and these are evidently of later age than the schists. Amphibolite layers between the schists may represent the remnants of former flows or intrusions of a basic magma. The rocks are similar in a general way to those in the vicinity of the Arizona Northern.

ORE DEPOSITS.

A fair exposure of the quartz veinlets is afforded by an opening on the south side of a ridge just south of the camp. Here is exposed a series of several parallel veins separated by schist. This series is about 25 feet in width, the largest single quartz vein being 4 feet wide, and it can be traced in a vertical distance 50 feet down the north side of the ridge where it disappears from view. These veins strike about S. 20° E. and stand quite straight, being slightly faulted, however, both horizontally and vertically. The quartz is pure white in places and bluish black elsewhere, containing invariably a considerable amount of siderite, a little specularite and pyrite, with calcite filling vugs and cross fissures in the veins. The quartz and siderite appear to have crystallized contemporaneously.

On the north side and below the top of the ridge, which is just south of the camp, occurs a true fissure vein about 10 inches wide. This strikes north-south and, although nearly vertical, dips a trifle east. The vein filling is composed almost entirely of quartz with a little iron oxide scattered throughout, and the vein is tightly frozen to its walls. Just below this opening, about 15 feet, as exposed in another open cut, the fissure is found to thin down to 1 inch.

In general the veins occupy the lamination planes in the rocks and occur in much the same manner as those in the vicinity of the Arizona Northern.

In the second wash south of the Yellow Bird camp and a short distance west of the Arizona Northern prospect are some diggings locally known as Dutch Henry's, which are reported to have produced several thousand dollars worth of gold. Here quartz veins occur in a schist series similar in many respects to that present in the vicinity of the Yellow Bird camp. One prominent vein dips due west, cutting the schists which dip southeast. In general, however, the ledges occupy the lamination planes of the schists and occur in several instances along the contact of diabase and slates.

Origin of the deposits.—It is possible that waters accompanying the intrusion of the granite which forms Salome Peak are responsible for the numerous quartz lenses found throughout this part of the Harcuvar Range. Although no free gold was seen at either locality just described, there has been, no doubt, a considerable amount extracted from the veins as well as from placer deposits below them, and it is highly probable that there are other places in the vicinity which will warrant prospecting.[a]

ARIZONA NORTHERN (SALOME STRIKE) VICINITY.

DEVELOPMENT AND LOCATION.

The finding of free gold in considerable quantities in small gash veins in this vicinity caused a small boom in the spring of 1909. Many people visited the prospect, and some staked out claims in the vicinity, although little actual assessment work had been done before the writer left the field. The developments on the strike itself are of the most meager nature, consisting only of a small surface cut in the mountain side. Because of the possibility of finding other gash veins in the vicinity a brief description will be given of the general conditions and geological relationships existing in this locality.

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[a] See discussion on future prospects in Arizona Northern vicinity, p. 101.

The Arizona Northern is in an air line just 5 miles a little east of north of Vicksburg, which station is not only the nearest but by far the most convenient to the property. Near the old Desert prospect, under the management of Josiah Winchester, a town of tents sprang up, bearing, while the boom lasted, the name of the promoter. This is just a trifle over 2 miles northeast of Vicksburg and was utilized as a stopping place by many of the people who visited the new strike. From the Desert property there are two ways of approaching the Arizona Northern vicinity. One is northeast up the canyon by a rough wagon road, which leads to within a mile or less of the strike, a trail having been built from this point to the prospect. The other way is by a good wagon road to the Yellow Bird prospect and then by trail from this place to the Arizona Northern. The nearest known water supply is at the Desert property.

TOPOGRAPHY.

Reference to figure 14 will show the type of country in the vicinity of the Arizona Northern, and Plate IV shows two views taken from the top of the mountain above the prospect. Rather prominent ridges are separated by deeply dissected valleys, which merge abruptly into the desert and there become obliterated. The sketch map was drawn from a point a short distance east of the prospect shown thereon, and the ridges north of this place were not examined. The difference in elevation between the top of the ridges and the valleys is approximately 800 feet, and the exposures of rock here, as elsewhere in the area, are very distinct. The opposite direction of dip of the schists on either side of the wash in the vicinity of the prospect suggests that the direction of the gulch may have been determined by faulting.

GEOLOGY.

The portion of the Harcuvar Range exposed to view in going from the Desert prospect to the Arizona Northern by way of Desert Canyon is essentially a sedimentary series of dark clay slates alternating with calcareous beds and arenaceous strata and including numerous amphibolitic beds of varying thickness. This series is intruded by later dikes, of which the principal types are aplite and minette.

The clay slates and allied rocks, some of which have been metamorphosed into fine-grained quartz-mica schists, are not greatly altered and where observed showed no evidence of contact metamorphism. The schistosity is well defined in the slates, and those of the pure clay variety are in part almost fissile enough for roofing materials. The more massive calcareous beds seem to have been less susceptible to the development of lamination planes than the slates, and in several places phenomena were seen indicating that the schistosity was not entirely coincident with the stratification. This was evidenced by the oblique angle between bedding planes in the massive strata and the schistose laminæ in the slates. The predominant colors are black, gray, and green, and the rocks, except the quartz-mica schists, are extremely fine grained.

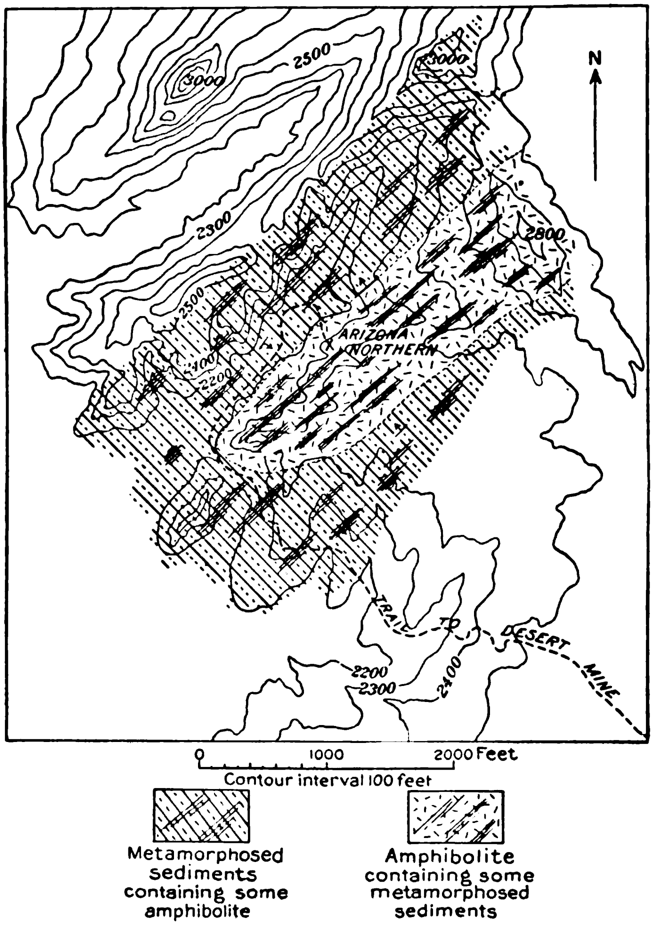
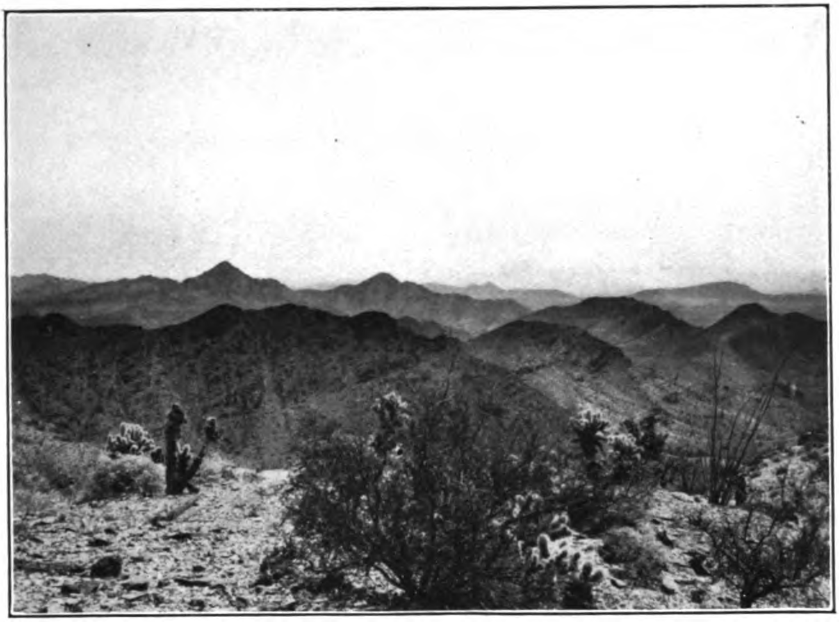
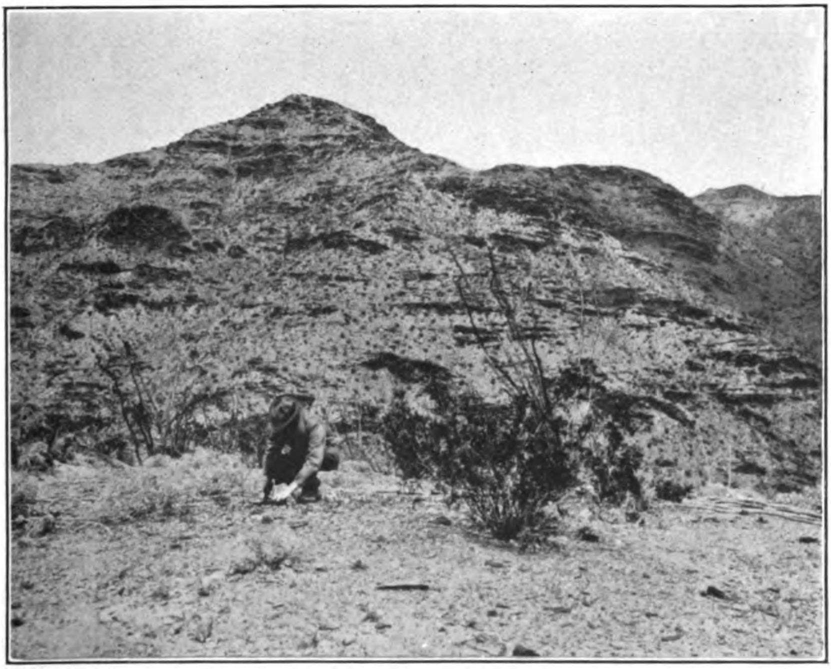

N
3000
2500
3000
2300
2800
2500
2100
2200
ARIZONA NORTHERN
TRAIL TO DESERT MINE
2200
2300
2400
0
1000
2000 Feet
Contour interval 100 feet
Metamorphosed sediments containing some amphibolite
Amphibolite containing some metamorphosed sediments

FIGURE 14.—Topographic and geologic sketch map of the vicinity of the Arizona Northern prospect.

Many of the amphibolite layers are only a foot or two in thickness, while some are massive, resembling fine-grained diabase, and these are schistose at the contact with slates. In general the amphibolite is greenish in color, is schistose, conforms to the strike and dip of the sedimentary series, and represents, perhaps, a succession of flows or intrusives into the complex before its schistosity had been developed. Reference to figure 14 will show the Arizona Northern as



A. RIDGES IN VICINITY OF ARIZONA NORTHERN PROPERTY.



B. PEAK JUST EAST OF ARIZONA NORTHERN PROPERTY

located in amphibolite of the massive type near its contact with slates, which are more or less continuous throughout the area mapped as amphibolite. Doubtless other localities in the vicinity contain massive amphibolite and probably have associated with it numerous veins similar to those found here. As only a very small part of the area was studied in detail, it is impossible to give information on this point, and the sketch map of this vicinity is complete only in so far as it deals with the immediate surroundings of the Arizona Northern prospect.

ORE-BEARING VEINS.

Included in this complex and in many places following the planes of schistosity are a great many quartz veins, generally irregular and often contorted. (See fig. 3, p. 39.) As a rule they are small and not continuous, although in places where it probably is nearly barren of gold values the quartz occurs in large masses. The small veins nearly always contain some siderite or allied carbonate, and occasionally chalcopyrite and galena are present. It was from small gash veins of this type that the Arizona Northern pocket was taken. Here free gold occurred in considerable quantities and in some of the best specimens seen by the writer constituted one-half of the ore. In general the free gold is rather sparingly distributed in the veins, and in several places where the writer knocked off pieces of ledge matter some distance away from the "Glory Hole" the free gold was only discovered after dissolving the iron oxide and carbonate present, which formed an effective covering for the gold. Specimens from an apparently barren ledge, which had not been prospected at all up to the time of the writer's last visit to the camp, showed some beautiful free gold after treatment with acid. This ledge is located about 50 feet in a vertical distance above the "Glory Hole," and apparently it cuts across the schistosity of the rocks. The gangue is composed principally of siderite and limonite, with a subordinate amount of quartz. The rock in which the ledge occurs is very calcareous, resembling a dolomite. This is apparently intercalated with amphibolite, as is the rest of the sedimentary series.

Origin of ores.—The gold in these veins may have been derived in part by the oxidation of pyrite, but most of it is probably primary. The veins are believed to have been formed after the probably Mesozoic intrusion of the large granite mass of Salome Peak, the nearest granite noted being about 1 mile distant.

Future prospects.—While the irregular character of the veins militates against deep mining, their frequent occurrence is conducive to mining to shallow depths and over large areas. Some of the gash veins might be profitably worked in a small stamp mill, provided the initial outlay of money were small. After the ground is proved, if it warrants the expenditure of large sums of money for machinery, then the vicinity could be worked on a larger scale.

DESERT PROSPECT.

The Desert prospect, operated by Josiah Winchester, is located 350 feet above and about 2 miles northeast of Vicksburg and has been well known for a number of years as situated near an old well, which has been the source of water supply for many of the properties in this locality. The gulches here, as elsewhere in the vicinity, have been prospected to some extent by dry washing, and it is no doubt due to the fact that some fairly good placers had been worked in these gulches that the adit tunnel on the property was driven, presumably in the hope of cutting gold-bearing ledges in place. Thus far this has not been accomplished.

The camp became known as "Winchester" shortly after the discovery of the Arizona Northern. A small, partly dismantled stamp mill is located near the mouth of the adit tunnel.

Arenaceous shales and argillites are the principal rocks in the vicinity. These contain intercalated amphibolite to a less degree than those in the vicinity of the Arizona Northern, and the series here is more calcareous, being traversed in places by veinlets of calcite. A very persistent dike of aplite cuts through the rocks just above the workings on the east and can be seen for several thousand feet to the north. It is probably connected in origin with the granite intrusion to the east. A number of basic dikes are seen in the vicinity.

Small stringers of quartz occupy openings in the sedimentary series, and in general follow the planes of schistosity. These show some mineralization, chiefly by limonite, although some chrysocolla and malachite, with a very small amount of cuprite are present, and a little chalcocite was noted. The placers which have been worked in this vicinity probably originated from the concentration of gold derived from these small quartz lenses. A short distance above the adit opening below the top of the small hill just back of the camp there is a large lens of quartz stained by malachite and limonite.

CALCITE PROSPECT.

In an air line the Calcite prospect is just 5 miles due west of Salome, the distance by wagon road being a little greater. The workings are located in a wash known as Desert Canyon and are a short distance west of the base of the range in the lower hills which form this part of the Harcuvar Range. At the time of the writer's visit (May, 1909) the vertical shaft had been sunk 150 feet and a level 40 feet long had been driven.

The geology is exceedingly interesting because of the late granitic intrusives, which have cut up through the metamorphosed sedimentary complex and still further changed its character. The granite which has so promiscuously invaded the southwestern part of the

Harcuvar Range is here present in various places, and has worked a decided change in the calcareous strata which are intercalated with the quartz-mica schists and the quartzites. Basic intrusives are also present, but these do not appear to have caused much alteration in the series. The calcareous rocks in places have been entirely silicified, and subsequently formed fissures have been filled by gypsum; and one stratum of this rock, 40 feet wide, highly impregnated with iron pyrite, is being explored for copper deposits by the Calcite Company. The pyrite is tarnished and stained in places so that it resembles bornite and chalcopyrite.

The lack of contact metamorphic minerals is indicative of a shallow depth or slight overlying weight at the time of the intrusion of the granite magma.

COBRALLA VICINITY.

The Cobralla is one of several properties located in the Tank Pass vicinity, and the writer regrets to state that it was the only one he had time to visit. With the exception of some drilling, which was being carried on at the Ultimatum, all of the prospects in the locality were idle. At the present writing (May, 1910) the principal development in the area seems to be in the vicinity of the Ultimatum, the work being carried on by the Tank Pass Consolidated Mines Company, which has taken over[a] the Cobralla and various other properties in the vicinity.

It is about 10 miles in a northwest direction from Salome to the Cobralla, the distance by wagon road being longer. Tank Pass, traversed in going to and from this property, is some 550 feet above the prospect and about 1,000 feet above Salome, and necessitates a steep haul in either direction. No large shipments have been made from this locality so far as the writer is aware.

The Cobralla is located in the end of a long, narrow ridge, which projects northward from the main mass of Salome Peak, and in traversing which granitic rocks are seen intruding a sedimentary series comparable in many respects to that seen in the vicinity of the Calcite. Here the intrusion appears to have taken place at a greater depth or under more pressure, contact metamorphic minerals having been developed on a large scale and limestone strata in places completely changed to wollastonite. Minette dikes were noted in the area where granite, later than the main mass which forms Salome Peak, has been intruded, and pegmatite and aplite dikes were seen which cut all formations. Along the contacts of granite with granite large hornblende and albite crystals have been developed. These are associated with some epidote and a little calcite.

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[a] Los Angeles Mining Review for November 24, 1909, Arizona correspondence; and various recent articles in the Arizona Mining Journal.

Medium-grained quartz-mica schists appear to underlie intercalated quartzite, limestone, and amphibolite strata which have been variously silicified. The directions of strike and dip are not constant over large areas, these changing from a strike of N. 70° W. and a dip of 30° SW., some 2,000 feet south of the Cobralla, to an east-west strike and a 30° N. dip about 1,000 feet south of the prospect, and to a 15° to 20° NE. dip and a northwest-southeast strike at one of the openings just northwest of the Cobralla house. In the immediate vicinity of the prospect holes the directions of dip and strike vary continuously and local folding and faulting are pronounced.

The Cobralla property has been prospected by a shallow shaft and several small surface cuts. In the shaft a zone of intense movement is shown, and the resulting brecciated schist fragments form the main part of the fracture filling. Here the fissure cuts directly across the schistosity of the rocks, and various contact metamorphic minerals are exposed. Epidote is the most prominent, and actinolite has been developed on a large scale. Magnetite is present in the limestone, and pseudomorphs of hematite after pyrite are noted in places. Vesuvianite is present in very small amounts, and garnet was seen in some of the specimens. The small amounts present of malachite, and the copper sulphide, chalcocite, are presumably derivatives of chalcopyrite and bornite of contact metamorphic origin, and these minerals seem to occur in larger amounts in the limestone than in the schists. Secondary quartz and calcite are abundant, filling small fractures and occurring in vugs; and the black oxide of manganese was noted on some of the specimens. Wollastonite occurs, overlying the schists in the open cut northwest of the Cobralla house.

Metalliferous ores are not abundant along this contact metamorphic zone, but possibly future developments in this and contiguous localities may prove more successful in uncovering copper ores.

DEPOSITS AT THE SOUTHWEST END OF THE HARQUAHALA MOUNTAINS.

PROPERTIES EXAMINED.

This part of the range is locally well known in that it contains the famous Bonanza mine, known for a time as the Harqua Hala. This property and the Golden Eagle, the Hercules, the Socorro, the San Marcos, and others have been worked for the gold values occurring in the deposits, and some remarkably rich ore has been extracted from the various workings. There are numerous other deposits in the Harquahala Mountains, but the five mentioned above were reported to have received the most prospecting, and they were, therefore, the only ones examined. Wenden and Salome are the railroad stations most accessible to these deposits, which are all located in the central part of the Ellsworth [a] or Harcuvar mining district. This part of the Harquahala Mountains is characterized by the presence of sedimentary strata, which constitute a large portion of the southwestern extension of the range.

BONANZA MINE (HARQUA HALA).

HISTORY, LOCATION, AND DEVELOPMENT.

History.—According to report the original prospect was located on November 14, 1888, by Messrs. Harry Wharton, Robert Stein, and Mike Sullivan. The property is said to have been sold in part to Messrs. Gray, Kirkland, and Corcoran, and in part to Mr. Hubbard, who bought out the other owners within a year. After taking a large sum from the mine, Mr. Hubbard is said to have sold it to an English company in 1893. According to report Mr. Hubbard bid in the property at auction in 1898, and later sold it to the Bonanza and Golden Eagle Mining Company. The property was then leased to the Harqua Hala Mining Company. Later the property reverted to the Bonanza and Golden Eagle Mining Company, which now controls it. Lessees are said to have produced considerable gold between the time Mr. Hubbard first worked the property and its sale to the English company. The total production of ore from the mine reaches $3,631,000.

Location.—The Bonanza mine is located at a place known as "Harqua Hala," in the extreme southwestern part of the Harquahala Mountains, near the base of Martin Peak, at an elevation of approximately 1,800 feet, and is, in an air line, 8 miles almost due south of Salome. A fair wagon road connects the mine with Salome, from which point supplies are shipped in.

General economic considerations.—Crude oil is used for fuel in the generation of power and costs $1.75 per barrel at Salome, the freight to the mine adding about 50 cents to this price. Timber costs $33 per thousand at the property. Mining costs naturally vary considerably. The Harqua Hala Company, when operating, reported a cost of $3 per ton for mining and milling. Water is obtained by a pipe line from Harrisburg.

Equipment.—The company owns two 20-horsepower hoists, one air compressor capable of running six drills, a 40-stamp mill,[b] (see Pl. V, *B*), an 80-horsepower engine, four 100-horsepower double boilers, two Blake crushers, and a 5,050-foot tramway, present capacity 10 tons per hour, connecting the Bonanza mill with the Golden Eagle mine (owned by the same company and located 1 mile north). Several dwellings and houses are located in the vicinity. The 30,000-

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[a] For map of mining districts see figure 4 (p. 45), prepared from official records by the county clerk of Yuma County.

[b] For partial description of mill see this report, p. 17.

foot pipe line from Harrisburg supplies the camp with all the necessary water, and for milling purposes much of the water from the mine has been utilized in the past.

Development.—A shaft inclined at an angle of approximately 60° and attaining the vertical depth of 205 feet below the collar, together with about 7,000 feet of levels, drifts, crosscuts, and winzes, constitute the principal development of the Bonanza mine. Plate VI shows a plan of the property. The main stoped area is reached from levels 3, 4, and 5, and below this the remaining levels 6 and 7 consist of long crosscuts. A large "glory hole," shown in Plate V, *A*, is the result of the caving of one of the big stopes. Numerous other workings, which are mainly shallow shafts, have been started at different places on the property.

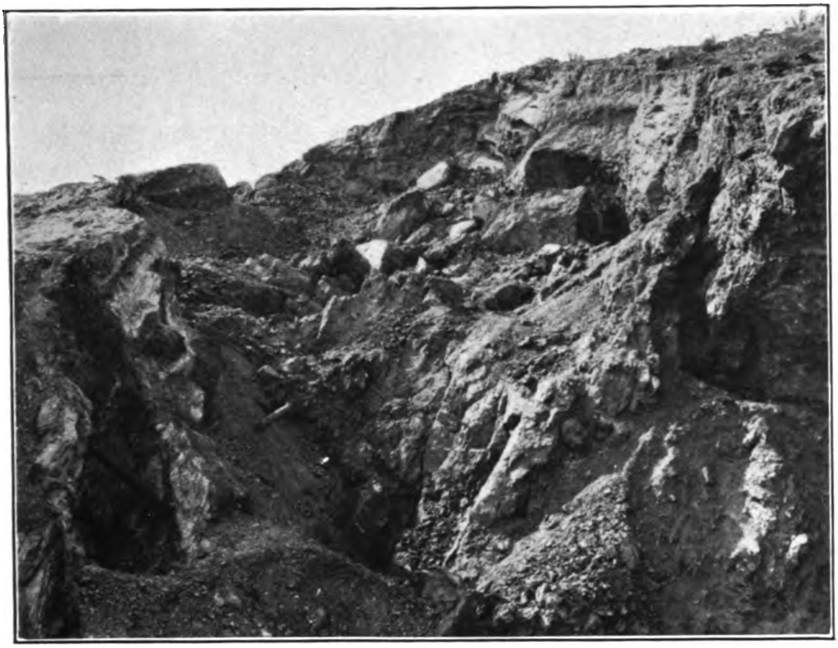
TOPOGRAPHY.

The Bonanza mine is located near the base of Martin Peak (shown in Pl. V, *B*) on its northeast side, and is a few feet above a wash, which drains south and east. The drainage is confined between two rather prominent ridges capped by peaks rising 600 feet or more above the wash, the ridges being separated from each other by about 2 miles. These peaks form the most prominent feature of the southwestern extension of the Harquahala Range and effectually conceal the workings of the Bonanza mine from any but a northern view.

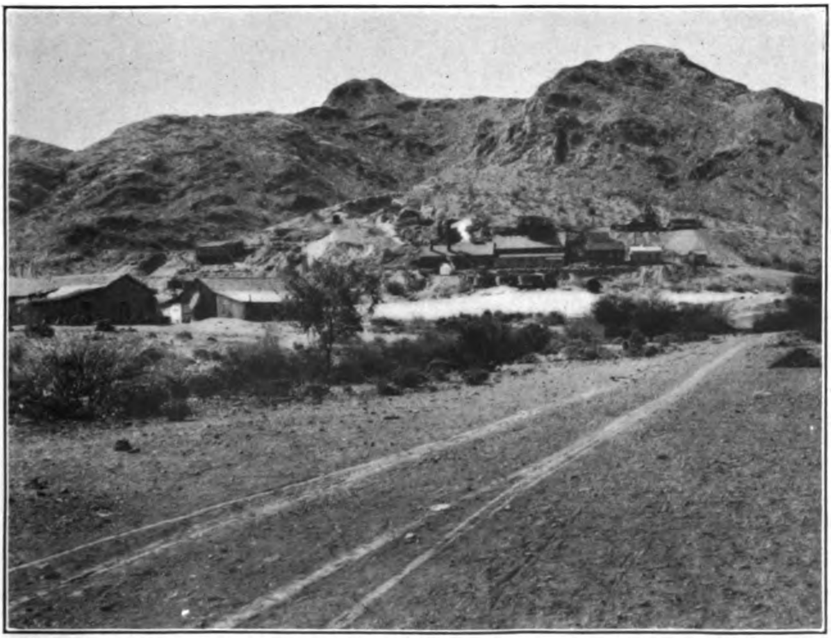
GEOLOGY.

The basal rock in the vicinity, which is not exposed on the surface near the mine, is rather coarse grained and has the composition of a granite. It is highly impregnated with pyrite. Just north of the Golden Eagle, which is 1 mile a little east of north of the Bonanza, the contact between the sedimentary series and this granitic base rock may be seen. The contact apparently runs in a general northerly direction and probably could be found a short distance northwest of the Bonanza. The eroded surface of this granite rock appears to dip southeast.

The sedimentary rocks in which the deposit occurs have a few feet of reddish quartzitic grits for a base. Over this lie 100 feet or more of intercalated limestone and argillaceous shale, above which is a thin conglomerate, capped by several hundred feet of schists and gray limestone, including a small thickness of dark-gray dolomite and thin beds of conglomerate. The whole series has been tilted in various directions and the dip near the top of the section appears to vary from 20° to 60° a little west of north. Marked divergences from this general direction were seen, and strata which dip southeast were noted near the base of the series. The presence of dolomite in this section is worthy of remark, little having been seen elsewhere in the area. A partial analysis by Chase Palmer, of the United States



A. CAVED STOPE IN BONANZA MINE.



B. PART OF HARQUAHALA, ARIZ., INCLUDING BUILDINGS OF THE BONANZA MINE.

Geological Survey, of a specimen taken near the base of Martin Peak gave 29.94 per cent CaO, 20.59 per cent MgO, and a loss of 47.03 per cent on ignition. Many of the dark-brown limestones throughout the area, especially those in the vicinity of the Planet and Signal properties, resemble dolomites. Analysis, however, shows that they contain hardly any magnesia.

The whole series is intruded by dark-colored basic dikes, and veinlets of quartz and calcite are found throughout the section.

ORE DEPOSIT.

At the present time there is not a great deal to see of the Bonanza ore deposit. Below the fifth level (see Pl. VI for plan of workings), which is under water level (that being 170 feet below the collar of the shaft), most of the work has been of an exploratory nature, and above this the stopes, drifts, and other workings have all been in the oxidized zone. Consequently only the skeleton remains of the pay portions of the deposit, which has been largely worked out. As viewed underground the ore shoots seem to have occupied zones of shearing extending through the sedimentary series of intercalated limestone, shale, and quartzite into the basal granitic formation. This is exposed in places in the lower workings on levels No. 6 and No. 7 and is a very coarse grained granitic looking rock, which has been severely crushed and fractured, and pyrite has been deposited along the brecciated zones, which are now filled with sericite, the latter presumably resulting from the decomposition of formerly existing feldspars. Figure 15 shows the relation of the fault planes as exposed in the "Castle Garden stope." The two main ore shoots represent a continuous shear zone on the east, striking approximately north-south and dipping at an angle of about 45° W., into which runs a lesser

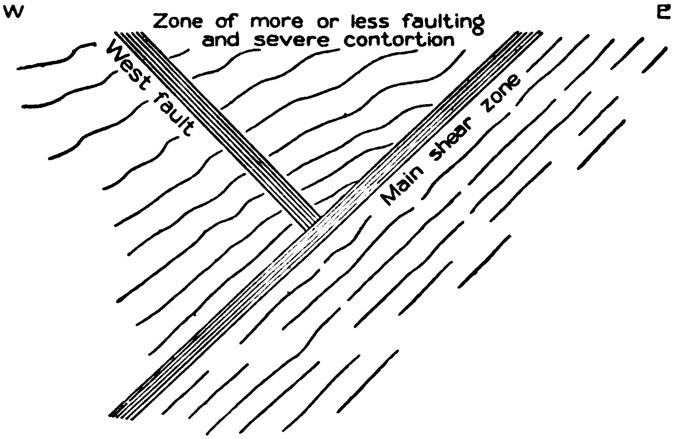


FIGURE 15.—Ideal section of part of the two principal veins exposed in the Castle Garden stope, Bonanza mine.

fault from the west, the strike being parallel to that of the others, while the dip is 45° E. The ore shoot on the west, however, has been more productive. These two main veins vary in width from a few inches up to many feet, and it is in the zone of movement that the gold values have been concentrated. Soft hematite of a deep-red color is omnipresent in the workings above water level, and this, with quartz, calcite, brecciated crushed country rock, and a little gypsum form the gangue minerals present in the croppings of the veins. Very rich pockets of gold are reported to have been found in various parts of the mine, and the writer was shown a good part of a large nugget, the original specimen having been reported to be worth $10,000. This particular piece showed large bunches of gold intimately associated with quartz. The quantity of silver found in the ore is remarkably small, and there is hardly any evidence of copper in the oxidized zone. Small quantities of galena have been found replacing dolomite in a shallow shaft located 500 feet southwest of the mine.

Future of the deposit.—On considering the fact that such a large production has been derived from the levels above the vertical depth of 170 feet together with the complete change of character of the veins below this depth, it seems reasonable to suppose that if there are any large ore shoots or pockets found in the future they will probably be above ground-water level along the strike of the shear zones rather than in those portions of the planes of movement which are now below the zone of oxidation. It may, however, be found possible to work profitably the pyrite which occurs in the shear zones in the granitic rock below the sediments.

Origin of the ores.—The gold values found in the workings above water level have probably resulted from concentration in the zone of oxidation of the gold content of the pyrite, which seems to have been introduced into the granitic rock after its brecciation, and was no doubt likewise present in the shear zones crossing the sedimentary series.

GOLDEN EAGLE PROPERTY.

There was no opportunity to visit the Golden Eagle property, and the following information has been taken from correspondence with the president of the Bonanza-Golden Eagle Mining Company:

The Golden Eagle is opened by an inclined shaft 400 feet long, dipping at an angle of 45°, and there are about 450 feet of drifts and crosscuts on the lower level where a body of ore carrying pyrite, chalcopyrite, and very small amounts of other copper sulphides has been encountered. Two assays of this ore made by John A. Hunter of the Congress Gold Mining Company and transmitted to the writer by Mr. Martin, president of the company owning the Golden Eagle,

show the following results: Copper, 0.25 and 4.84 per cent; silver, 1.32 and 2.88 ounces per ton; gold, 0.48 and 1.12 ounces per ton. Mr. Martin states that the ore above the 300-foot level was free milling and that it has been stoped out.

HERCULES PROPERTY.

LOCATION AND DEVELOPMENT.

This property is nearly equidistant from Salome and Wenden, being in a direct line about one-half mile nearer the latter place, and 3½ miles almost due south of it. Salome is just 4 miles in an air line a little north of due west of the Hercules property, and good wagon roads connect the property with both stations, the length of these roads being approximately 5 miles. The prospect is located at an elevation of about 2,100 feet and is near the end of the extreme northwestern projection of the Harquahala Range east of Centennial Wash.

The property has been developed by two shallow inclined shafts, one located several hundred feet east of the other, and these are connected underground by one level. The shafts dip about 60° N. and presumably have been started with a view to following down the vein.

The total production of the Hercules Company is said to be about $10,000. Good dwellings have been erected on the ground, some machinery is installed, and water is pumped through a pipe line to the camp.

GEOLOGY.

Coarse-grained quartz diorite gneiss contains the veins which have been worked on the property. This rock is present in various phases for some little distance to the west, the Prince claim having been located and prospected about one-fourth mile west of the Hercules in a finer grained phase of the same formation. This quartz diorite was intruded by a fine to medium grained quartz-mica rock of granitic or dioritic composition, and both are overlain by fine-grained calcareous quartz-mica schists and quartzites. Figure 16, sketched from the top of the quartzite knoll, shows the geologic relations in a general way, and Plate VII, *A*, illustrates the manner in which the metamorphosed sediments overlie the quartz diorite gneiss and medium-grained quartz-mica schist. Schistose structure has been induced in all of these rocks except the quartzites and the later diabase intrusives. Some of the strata included in the quartz-mica schists are so calcareous that they resemble limestones. Examination of these so-called limestones under the microscope reveals the presence of much quartz and mica with only a subordinate amount of calcium carbonate.

ORE BODY.

Lenticular veins of quartz occur in the quartz diorite gneiss. As exposed in the eastern shaft, the quartz vein varies in width from 8 to 24 inches and appears to occupy a shear zone in the country rock. The strike of the vein here is S. 75° W. and the dip is about 60° N. The vein filling is brecciated to some extent and shows banded structure of quartz and jasper with fragments of both cemented by limonite. The gold values are obtained from the highly iron-stained quartz masses and are probably derived by oxidation of auriferous pyrite.

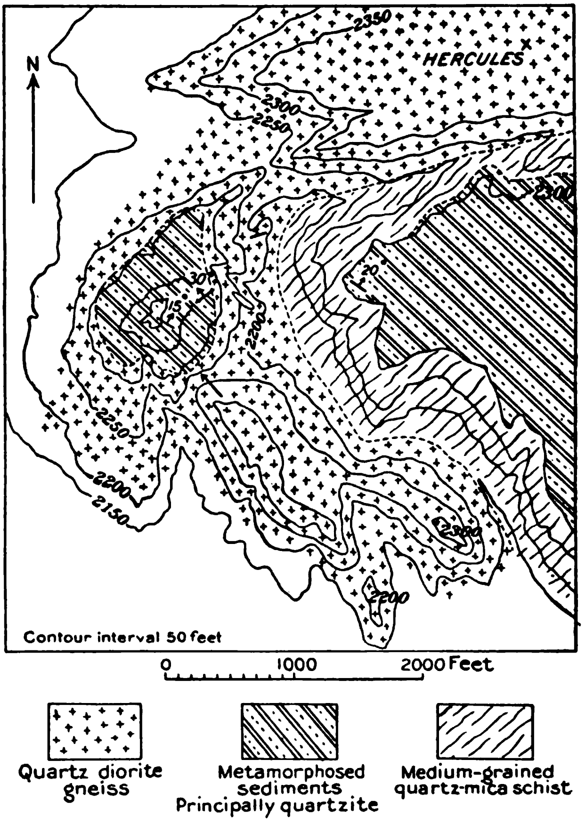


FIGURE 16.—Topographic and geologic sketch map of the area just south of the Hercules property.

Reference to figure 17, which represents one wall of a stope in the Prince claim about one-fourth mile west of the Hercules, will help in understanding the character of these deposits. There is little continuity to the quartz lenses, postmineral faulting having taken place along both the dip and the strike of the veins.

A. VIEW NEAR HERCULES MINE, SHOWING CONTACT OF METAMORPHOSED ROCKS WITH UNDERLYING QUARTZ DIORITE GNEISS.

B. VIEW NEAR CUNNINGHAM PASS MINE, SHOWING INTRUSIVE DIABASE IN GNEISS.

SOCORRO PROPERTY.

LOCATION AND DEVELOPMENT.

This property is located on the southern side of the Harquahala Mountains at an elevation of about 2,000 feet, and, in an air line, is just 10 miles southeast of Salome, with which place it is connected by wagon road. A mill [a] has been erected upon the property and this, with an assay office, shaft house, power plant, and several dwellings constitutes the surface improvements.

The deposit has been developed by a shaft over 325 feet deep, inclined at an angle of 26° N., in which water was standing near the 250-foot level when the property was examined by the writer. This is about 110 feet in a vertical distance below the collar of the shaft. From the shaft several short levels have been run about 300 feet, and some stoping has been done.

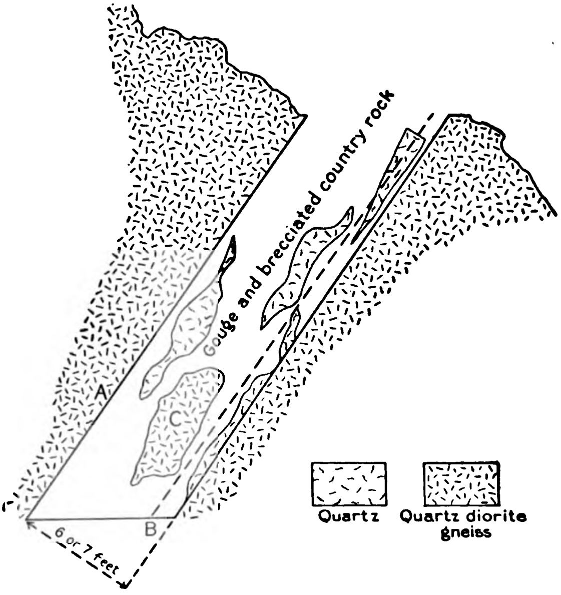


FIGURE 17.—Diagram showing character of the ore body in the Prince claim. A, Faulting along here formed vein; B, postmineral plane of movement at right angle to dip of vein—that is, along the strike; C, horse of country rock.

GEOLOGY.

Coarse-grained granite which shows some schistosity is the basal rock in this locality and is similar to the pre-Cambrian granite so universally present in this area. Resting unconformably upon the granitic rock is a series of slightly metamorphosed sediments of which about 150 feet of fine-grained grayish-red quartzite forms the base.

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[a] For description of mill and cyanide process see Trans. Am. Inst. Min. Eng., vol. 37, 1907, p. 570, article by F. C. Smith on the cyanidation of raw pyritic concentrates.

This is overlain by several hundred feet of yellowish-brown limestone, the upper portion of which contains intercalated argillites and quartz-mica schists. Strata of schistose shaly limestone and a rock very closely resembling a dolomite (containing, however, fragments of quartz) were noticed near the contact of the quartzite and the overlying limestone. A great number of pseudomorphs of hematite after pyrite were noted in parts of the basal granite in the vicinity and also in a rock near the contact between limestone and quartzite in the ridge just south of the shaft house. One specimen of quartz-mica schist taken from the dump and reported to have come from the 325-foot level about 350 feet south of the shaft shows abundant amounts of tourmaline and pyrite scattered through it. The whole sedimentary series has been tilted so that it now occupies diverse positions. The prevalent direction of dip, however, is east or southeast, the amount varying from 30° to 80°. Faulting has also taken place on a large scale. Small quartz veins are present in all of the formations, and calcite veins are not uncommon in the fractured limestone. A minette dike similar to that seen in the Valensuella workings was noted cutting the limestone on the ridge projecting southward from the mine, and this is possibly an accompaniment of the main granite intrusion found several miles farther west.

ORE DEPOSIT.

A large quartz vein occupying a fissure, which starts in the basal granite and extends out into the sedimentary series underground, forms the ore deposit. This vein strikes in an east-west direction and dips at a rather flat angle, about 26° N. The width varies from practically nothing up to several feet, the horizontal extent as defined in the workings is probably not over 300 feet, and the depth to which the vein has been followed is uncertain, as the lower workings were inaccessible. Above the 250-foot level, practically all of the quartz is highly iron-stained and oxidized ores which were free milling have been worked. Below this level pyrite containing gold forms the principal ore, and this in the past has been cyanided. In places massive pockets of pyrite are encountered, although this is exceptional, as the distribution of this mineral is rather scattered; the country rock here and there is highly impregnated with it.

The vein material shows considerable brecciation and recementation by siliceous solutions, pure white quartz being the predominant gangue, with some jasper. A little limonite was noted in this quartz. Vugs and drusy cavities lined with quartz are common, and free gold was noted in some of the cavities. The ores contain also some silver[a] and a minute amount of copper from covellite. A little galena was observed in slips in the limestone exposed by a short adit tunnel in the ridge south of the shaft.

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[a] See Trans. Am. Inst. Min. Eng., vol. 37, 1907, p. 570.

Origin of ores.—Siliceous solutions carrying pyrite were probably introduced under severe pressure into this series of rocks following the intrusion of granite, which took place some little distance farther west and fingers of which no doubt extend for long distances under the surrounding country. The presence of the minette dike, the numerous quartz veins, the intimate association of tourmaline in the schists, and the abundant quantities of pyrite occurring in the rocks in the vicinity are all indicative of the results of solutions accompanying granitic intrusion. Superficial oxidation has concentrated above ground-water level the values in the pyrite in this zone, below which level unaltered pyrite will probably be the future gold ore here as elsewhere in similar deposits in the southwestern part of the Harquahala Range.

SAN MARCOS DEPOSIT.

LOCATION AND DEVELOPMENT.

The San Marcos property, owned by the Pittsburg Harqua Hala Gold Mining Company, is, as regards transportation, one of the most accessible in the area. Wenden, the nearest railroad station, is just 4.1 miles in an air line northwest of the San Marcos, the distance by a good wagon road between the two places being approximately 5 miles, with an easy grade, and the camp is about 450 feet above the station. The total production up to May, 1909, is reported as about $10,000,[a] the majority of this having been prior to 1906.

A shaft inclined at an angle of about 30° NW., between 450 and 500 feet long, and 4 levels 100 feet apart on the incline, constituting in all some 1,700 feet of workings, make up the underground development on the San Marcos property. Figure 18 represents a plan of the shaft and levels.

A small but substantial camp has been built on the property, and these buildings, including a shaft house and a 12-horsepower hoist, constitute the present equipment of the camp.

GEOLOGY.

The rocks in the vicinity of the San Marcos are granites, probably of pre-Cambrian age, which have been intruded by basic dikes; parts of the series have been subsequently sheared, so that the granites are partially schistose and in places are massive. Coarse-grained rocks of aplitic composition have apparently intruded the older granites, and in these no schistose structure is observable. The basic amphibolites are sheared beyond recognition in places and are there represented by a soft earthy material quite unlike the original rock.

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[a] Superintendent Carr reports that 300 tons of ore were milled in October, 1909, which returned $8 per ton on the plates.

Faulting is pronounced, as in other prospects of this type in this locality.

ORE DEPOSIT.

Because of the very gentle dip to the shear zone in which the deposit occurs, the oxidized zone will have a greater linear extent downward, and, as the higher values occur in the zone of surficial oxidation in deposits of this type, the gentle dip is a favorable feature. As shown in the shaft between the collar and a point a few feet above No. 1 level the vein varies from 18 to 24 inches in width and has in the past yielded some exceptionally high grade ore. The gangue is principally quartz and brecciated country rock with a great deal of iron oxide mixed with it, and an occasional flake of specularite. The values are almost entirely in gold, which carries only a very small quantity of silver. No sulphides were seen in the property, everything above the bottom level being oxidized. When the property was visited the fourth and lowest level was under water. Just before reaching the first level the vein apparently disappears in the roof and, as this has

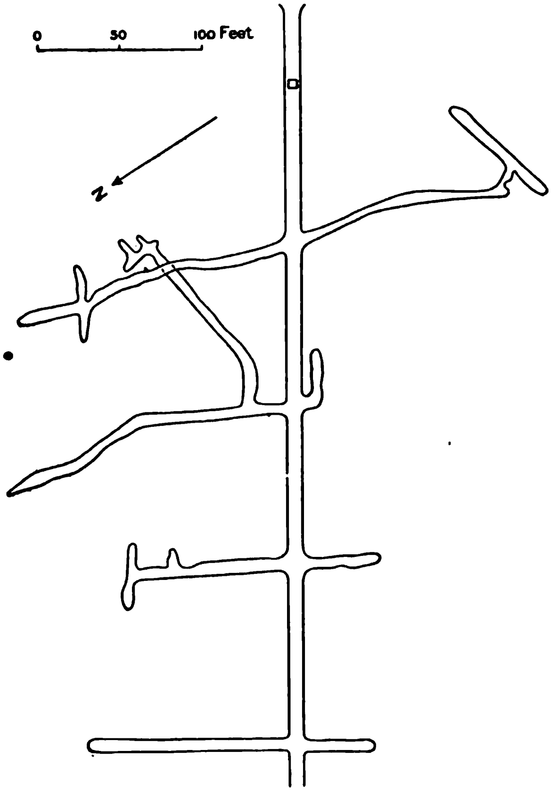

FIGURE 18.—Plan of workings of San Marcos property.

not been explored to any extent, it is impossible to say whether it has pinched out or simply flattened.

Below No. 1 level several small lenses of quartz have been discovered which carry values, but they are not continuous and are probably analogous to the lenses found in the Prince claim, west of the Hercules, a diagram of which appears on page 111 of this report.

MISCELLANEOUS DEPOSITS.

Under this heading deposits in the Cunningham Pass, Bullard Peak, Corona, McCracken, and Planet Peak vicinities will be discussed. These are here grouped together, not because of any similarity in mode of occurrence, but rather because of their geographic location, which prohibited their incorporation in any of the six groups which have just been described. All have been prospected as copper deposits except the McCracken, that having been in the past a silver-lead deposit of some note.

CUNNINGHAM PASS VICINITY.

GENERAL GEOLOGIC FEATURES.

There are numerous prospects in this locality, but the only one that was actively shipping at the time of the writer's visit was the Critic, of the Cunningham Pass Copper Company. This immediate vicinity was therefore studied in some detail, deposits on several claims belonging to the company being examined in a cursory manner. Hence the following description deals principally with the properties belonging to the Cunningham Pass Copper Company.

The rocks exposed in this vicinity typify the pre-Cambrian granite gneiss schist complex referred to in a preceding chapter on the geology of the region. Here a vast thickness of the series represents normal mica orthoclase granite, changing abruptly into gneiss and including between the layers of gneiss the resulting schistose phases of former basic intrusives. The whole series, which is composed principally of gneiss and schist, is cut by innumerable dikes of pegmatite and aplite, with here and there prominent diabase intrusives. Plate VII, *B* (p. 110), shows the relation of the later intrusive diabase in the gneiss, and Plate VIII, *A* (p. 118), shows in the foreground the head frame and dump on the Critic workings, in the background the portion of the Harcuvar Range just northeast of Cunningham Pass. In the ridge in which the Critic and Boone workings are located the planes of schistosity dip at a flat angle approximately 15° NW. In the hills northeast across the wash the dip is northeast, and there seems to be no marked regularity in small areas, although in general the lamination planes in the whole range northeast of Cunningham Pass dip slightly southeast.

CUNNINGHAM PASS MINE.

LOCATION AND DEVELOPMENT.

The property of the Cunningham Pass Copper Mining Company is in the Ellsworth[a] or Harcuvar mining district and is located, as the name implies, near Cunningham Pass, the Critic shaft being just 5,000 feet N. 70° W. of it. In an air line, Wenden, the nearest and most accessible railroad station, is just 8¼ miles almost due south of the Critic shaft, the distance by wagon road being approximately 11 miles. This road involves a steep rise of 400 feet over the pass going to Wenden and a rise of about 700 feet in returning.

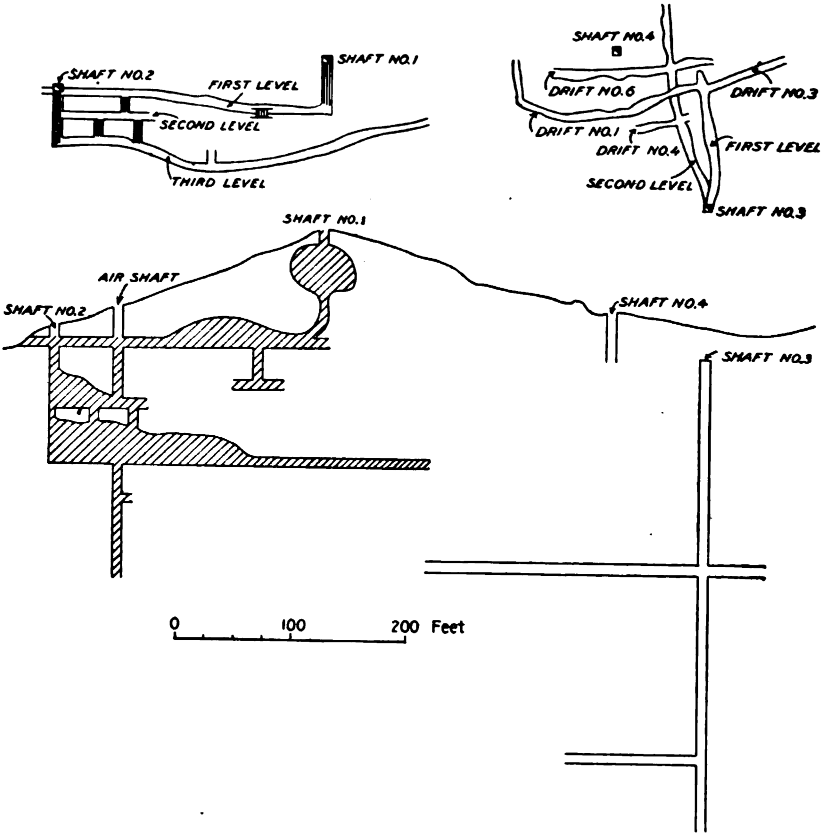

FIGURE 19.—Plan and section of the workings on the Critic claim, Cunningham Pass Copper Mining Company.

Freight on ore from the property to Wenden costs $4 per ton; the back haul is $3 per ton. Distillate is used for motive power in driving the hoist, compressor, and small blower, and the cost of this, including freight to the property, is 15 cents a gallon when bought in carload lots. Lumber costs $32 per thousand at the mine. Water for domestic use is obtained from two surface wells in the locality, and considerable water for other purposes is obtained from the shaft. The general manager of the company states that ore can be mined for $2.50 per ton. The company holds 13 claims, one of which, the Critic, is patented. Several buildings of a substantial nature constitute the surface improvements at the property. The machinery installed consists of a 12-horsepower hoist, a compressor capable of running four 2¼-inch drills, driven by a 40-horsepower engine, and a small blower driven by a 2-horsepower engine.

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[a] For map of mining districts see figure 4 (p. 45), compiled from official records by the clerk of Yuma County, Ariz.

Shallow shafts have been sunk on all of the claims held by the company; the main development, however, has been carried on in prospecting the Critic claim. Here the Boone and Critic workings are located, the former representing the original prospect and the latter a more extensive development of what the management considers an extension of the northeast Boone vein. Figure 19 shows a plan and section of the underground development which totals 2,000 feet on this claim. The new vertical shaft is down nearly 400 feet, and the two main levels and accompanying drifts total 1,050 feet, of which 330[a] feet represent drifts on the Critic vein. Not much stoping has been done from these drifts. The Boone workings represent a total of 950 feet of development work, including two inclined shafts pitching at a very steep angle, three levels, winzes, etc. A large part of the ore shipped from this property has been taken from the Boone workings. The total production of the Cunningham Pass Copper Company up to April, 1909, has been between 600 and 700 tons of ore, which averaged about 12 per cent copper and carried from one-half to 1 ounce of gold per ton.

ORE DEPOSIT.

As shown in the Boone and Critic workings the ore deposit occupies a true fissure cutting directly across the schistosity of the country rocks. The width of the vein varies from a few inches up to 3 or 4 feet and the ore-bearing streak is likewise as inconstant in its dimensions, changing abruptly in places from a barren vein into several inches of ore and again pinching out as suddenly. This is probably due to post-mineral longitudinal faulting, both horizontal and vertical, which is very much in evidence in the property, with the result that the deposits are pinched in several places. In figure 20, *A* is a sketch of the breast of No. 9 drift from No. 2 level, drawn in March, 1909; *B* shows the vein in a stope a few feet above No. 6 drift from No. 2 level; and *C* represents the breast of the drift a short distance beyond. After this drift had been advanced a few feet, a good showing of chalcocite was exposed, which with a little further drifting shortly dwindled down to a very lean streak. The country rock on both sides of the vein is fresh, although in a few places where faulting has been pronounced the schists are mineralized, principally by pyrite and hematite, the latter seeming to occupy every conceivable fracture in the rocks. Some of the pegmatites in the rock show mineralization, chiefly by stains of copper and iron, and the fractures of the aplite dikes are filled with hematite.

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[a] In May, 1910, probably 100 feet more of drifting has been done on drifts Nos. 6 and 9 since the property was examined in March, 1909.

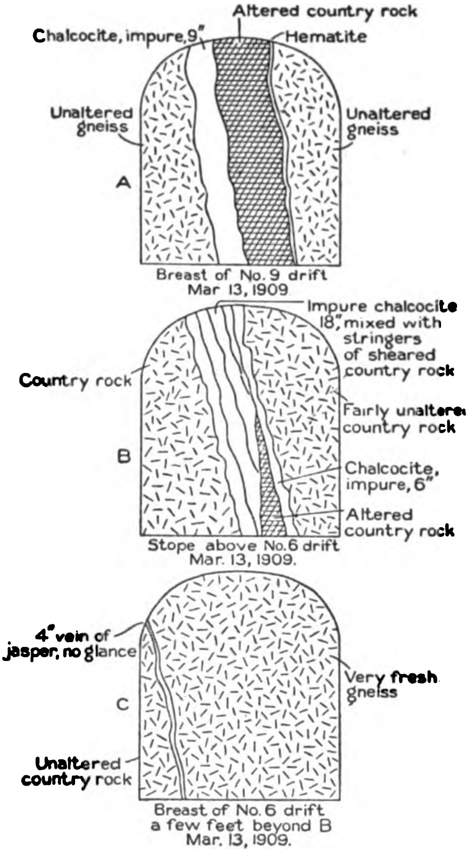
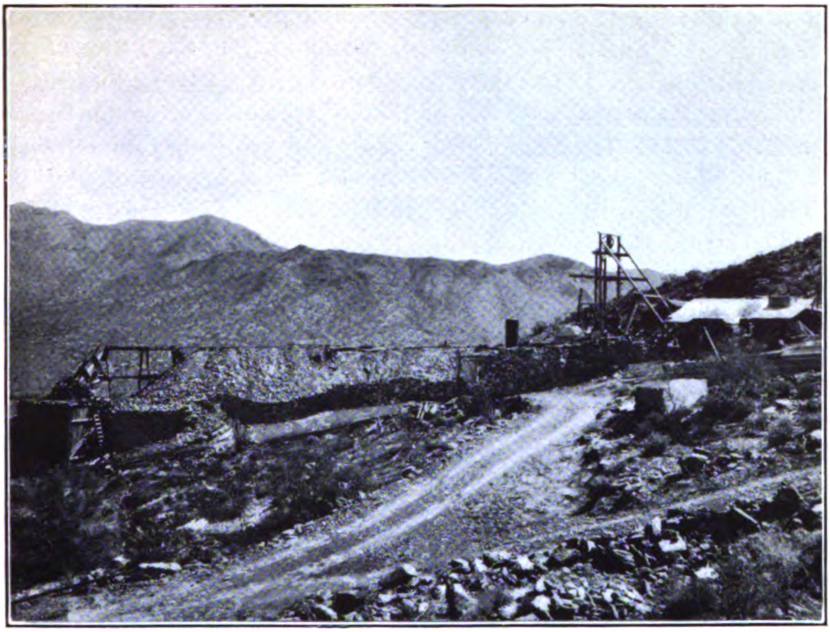
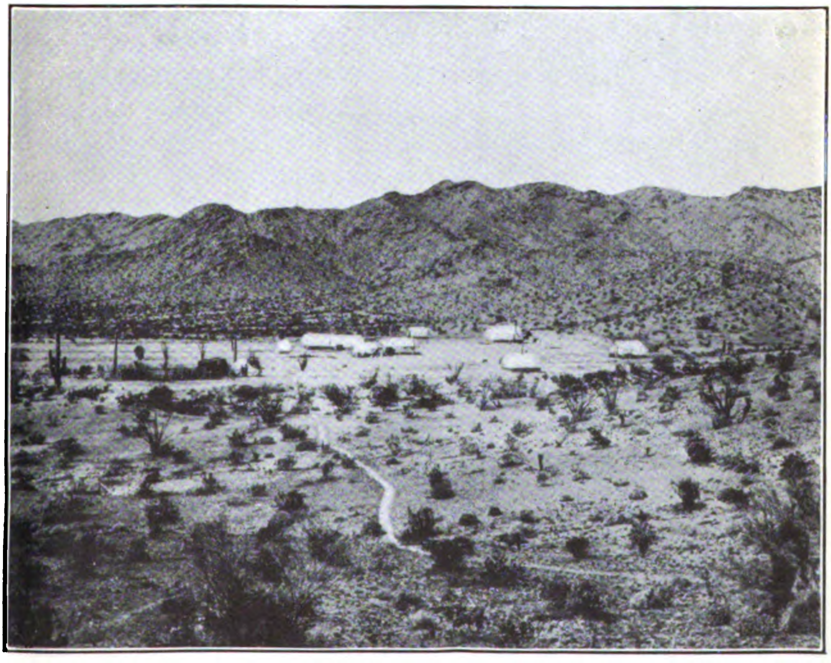


FIGURE 20.—Three sections of the Critic vein, Cunningham Pass Copper Mining Company.

The strike of the Critic vein is N. 50° to 60° W. and the dip is fairly steep, pitching 70° to 80° SW. The gangue is principally brecciated country rock and soft red hematite, with some specularite and limonite. Quartz is present in large quantities and occurs also in vugs, and occasional veinlets of calcite and barite were noted filling post-mineral fractures. In the zone above ground-water level the chief ore minerals are chrysocolla and chalcopyrite, with which are associated a little malachite, cuprite, and some chalcocite. Below water level, which is at a depth of 320 feet in shaft No. 3, the chief ore mineral is chalcocite, with which are associated some chalcopyrite and pyrite. Quartz is prominent as a gangue mineral and in places contains magnetite. The ore here does not occur as massive pure chalcocite, but contains much silica, and this in the form of jasper and quartz is distributed throughout the ore, which is porous, many of the cavities being lined with quartz crystals. Sorted ore from the workings near the surface contains an average of 50 to 60 per cent silica, 10 to 14 per cent iron, 1 to 1.6 per cent sulphur, 12 per cent copper, and one-half to 1 ounce of gold per ton. Lower down in the vein the silica in the ore seems to increase, in some cases attaining a percentage of 75 in sorted ore that has been shipped. The soft red hematite is reported by the general manager



A. HEAD FRAME, DUMP, AND OTHER FEATURES AT CRITIC SHAFT, CUNNINGHAM PASS MINE.



B. CAMP OF CORONA COPPER COMPANY.

Hills in background show schistose structure.

to contain from 1 to 2 per cent copper and from $10 to $20 in gold per ton.

Origin of the ores.—Apparently the ores have been derived from the leaching and the subsequent concentration of values contained in pyrite and chalcopyrite, this in all probability being the source of the gold values and the chalcocite found in the vein. Presumably this secondary enrichment of copper glance has been accomplished by downward moving waters.

Many ledges of impure siliceous hematite, some of considerable thickness, were observed in the vicinity, both on property belonging to the Cunningham Pass Copper Mining Company and on ground northeast of the camp. It is possible that a chalcocite zone may be found below some of these ledges.

BULLARD PEAK VICINITY.

LOCATION AND DEVELOPMENT.

The peak which is known throughout this part of Arizona as "Bullard's" is a small knob projecting about 300 feet above the desert. It is separated from the main mass of the Harcuvar Range by a shallow wash, which on the north seems to have followed the line of contact between the older underlying pre-Cambrian rocks and the comparatively young lava, of which a small remnant forms Bullard Peak.

This locality is in the Ellsworth or Harcuvar mining district, on the extreme eastern border of the area under reconnaissance and is nearly 10 miles in a direct line a little east of north of Golden, where no railroad station is maintained. The town nearest Bullard's is Wenden, 21 miles southwest in an air line and about 25 miles by wagon road. Near Bullard Peak a company once known as the Yuma Copper Company[a] operated for a short time a small smelter and worked ore from prospects near by.

Water is obtained from a well a short distance northeast. The prospects are located in the peak, near the top.

Various shallow inclined shafts have been sunk, and some drifting has been done. The property was idle when examined, and hence much information was not available. No machinery is installed, and the work in the past has been done entirely by hand.

GEOLOGY.

The oldest rocks in the vicinity are of the pre-Cambrian granite gneiss schist complex, which forms the Harcuvar Range east of the peak called by that name. These dip southeast at angles varying from 15° to 30° and are overlain near their contact with the surrounding desert by the material which forms Bullard Peak. The base of this peak is a conglomerate about 75 or 100 feet thick, composed of fragments of various sorts, principally andesitic. On top of this is about the same thickness of tuff, and this is capped by a few feet of bluish-green and brown augite andesite, which in the field somewhat resembles basalt. Examination of thin sections fails to reveal any olivine, although the rocks may once have contained some. In this rock occur the ore deposits.

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[a] Not to be confused with a company of the same name now operating north of Vicksburg.

ORE DEPOSIT.

The deposit occupies a simple fissure in augite andesite. This vein has a dip of about 45° in a southerly direction and varies in width from 18 inches up to 4 feet, the ore course having an average width of 6 inches, ranging up to 12 inches in places. Quartz and calcite form the gangue, the latter occurring also in small stringers traversing the andesite in all directions. Some hematite was noted and epidote is present in places in the country rock. The principal ore mineral is chrysocolla, and with this occurs some malachite, a little copper glance, and a small showing of cuprite. The vein shows brecciation and subsequent cementation by siliceous material. The ore has probably been derived from chalcopyrite, and the deposit is clearly of Tertiary age.

CORONA VICINITY.

LOCATION AND DEVELOPMENT.

The properties examined which have been prospected in this locality belong to the Corona Copper Company and are located in the Santa Maria or Bill Williams mining district, 20 miles in a direct line northwest of Wenden, the wagon road between the two places being 23.4 miles long. Bouse is only 16 miles southwest of this camp, but at present is not connected by wagon road. Water for the camp is obtained from a well about 1 mile southeast of the camp.

The company holds 54 claims, none of which are patented and only three of which have been actively prospected. These are the Mammoth, the Chicago, and the Copper Glance, which were located by Mr. Butler about fifteen years ago and relocated by him in 1908. One carload of ore has been shipped from the Copper Glance which is reported to have carried 22 per cent copper and from $4 to $5 in gold to the ton.

On the Chicago claim an adit tunnel has been driven for a distance of 400 feet, including a short crosscut, and a shaft has been sunk 125 feet. The Copper Glance workings consist of a small surface cut and an inclined shaft about 200 feet deep. The Mammoth claim is developed by a short inclined shaft and a level connecting with an upraise to the surface. The camp is composed of a few tents, and no machinery has been installed on the prospects. Plate VIII, *B* (p. 118), shows the Corona camp with the mountains of gneiss in the ackground.

GEOLOGY.

Gneiss and schist apparently of granitic origin constitute the oldest rocks in the vicinity and are probably of pre-Cambrian age. These are cut by intrusions of pegmatite, aplite, and a slightly schistose rock having the composition of a diabase, which is now an amphibolite. The Chicago and Copper Glance workings are located in rocks of these types. The gneiss has a general southerly dip, although many changes from this direction are apparent. Just east of the camp there is a small butte not over 100 feet in height above the desert and about 1 mile long, composed of brecciated material which very much resembles a conglomerate near the base and a granitic breccia above. This has the appearance of being the remnant of a detrital deposit formed from the erosion near at hand of granitic material, and the age of the formation is decidedly uncertain. In the section on general geology this was provisionally classed as Tertiary. This butte rests upon the uneven eroded surface of the gneiss and schist. Because of the large amount of iron oxide present in the cementing material of the breccia, the butte has a reddish-brown tone and forms a conspicuous topographic feature. The Mammoth workings are located at the base of this butte on its contact with the underlying gneiss schist complex.

CHICAGO DEPOSIT.

This deposit is located about eight-tenths of a mile N. 70° W. from the Corona camp and seems to occupy a slightly mineralized fault plane of no great magnitude in the gneiss. The strike of the vein is S. 35° E. and the dip is 80° to 90° NE. The shaft is located at an elevation of 1,860 feet, and the portal of the adit tunnel is some 15 feet higher up. The vein is only a few inches wide and is filled principally with barite, associated with which is some quartz, both occurring also as linings in vugs. A little fluorite was noted in the vein, and hematite is a conspicuous feature not only in the deposit, but also in the aplite dikes which are a common accessory of the gneiss schist complex. Brecciation of the country rock is a noticeable feature, and thin films of barite occur as a covering to these fragments. In places slickensided surfaces of gangue material were noted, showing post-mineral movement as well as that which occurred before. The vein is very sparsely mineralized with chrysocolla, and dioptase is reported as present in the deposit.

COPPER GLANCE DEPOSIT.

This is similar in many respects to the Chicago. The geologic section is identical and the mineralization more extensive. An inclined shaft is sunk on a small vein which strikes S. 52° E. and dips 60° NE. to a depth of 140 feet, where a post-mineral basic dike shatters the vein, which seems to spread out in several very small stringers.

Below this point the shaft is inclined 45°, and reaches water level at a depth of 171 feet, below which exploration is not extensive.

The vein itself occupies a shear zone in the country rocks and is of relatively small proportions, being only a few inches wide. The gangue is quartz and hematite with a very little magnetite, and a small amount of epidote and chlorite were noticed in the vein. The ore minerals are chiefly copper silicate and a little chalcopyrite. Copper glance is said to occur in this shaft at a depth of 190 feet.

Origin of the ores.—Concentration by oxidation of lean primary ores would be sufficient to account for these small deposits. The presence of barite and fluorite indicates a late introduction, and solutions bringing in these minerals are possibly the ones which have accomplished the concentration.

MAMMOTH DEPOSIT.

This deposit differs from others in the vicinity in that it occurs, as already noted, between the underlying gneiss schist complex and the overlying granitic breccia. The actual contact between the two formations is separated by a few feet of fine-grained material cementing small fragments of rock, and this takes the form of a consolidated silt, dipping 30° SW. Solutions carrying iron and a little copper have percolated through this more or less porous medium between the two formations with a resulting deposition of considerable red iron oxide and a small amount of copper silicate. Quartz, a little barite, and traces of fluorite were noted in the vein.

PLANET PEAK VICINITY ON THE SOUTHWEST.

PROPERTIES EXAMINED.

There are many prospects in this general locality, among which the Dome City, the Mineral Zone, the Mail Pouch, and the Pride, were examined in a cursory manner. These are all located in the Santa Maria or Bill Williams mining district[a] within a short distance of one another and are near a place locally known as Osbourne's Well, where water is obtainable. Parker is at present the most accessible town, but the active operation of the Arizona and Swansea Railroad will afford easier methods of approach. The properties have been but scantily prospected, shallow shafts and surface cuts representing the principal development. No large shipments are known to have been made from any of the above-mentioned workings.

GEOLOGY.

Gneiss and schist, presumably of pre-Cambrian age, form the oldest rocks in the vicinity, and all of the deposits examined in this locality except the Pride, occur in these rocks. Aplite, pegmatite, and basic dikes were noted cutting the formation. About 2½ miles northeast of Osbourne's Well, limestone, associated with the intercalated amphibolite, overlies the older gneiss schist complex, and in this series occurs the Pride deposit.

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[a] For map of mining districts see figure 4 (p. 45), prepared from official records by the clerk of Yuma County, Ariz. The Mineral Zone, Dome City, and Mail Pouch are located between the Ogden and the Pride prospects, both of which are shown on Plate I (in pocket).

PRIDE.

The Pride deposit resembles on a small scale those seen at Planet. Limestone has been partially replaced by hematite, with which is associated a little copper silicate. A 50-foot shaft has been sunk in the limestone, which is reported to show ore at the bottom. Several adit tunnels have been driven farther up in the series, and these disclose a small amount of mineralization along the joint planes in the amphibolite schist. The limestone dips in general about 15° to 20° S.

MAIL POUCH.

This deposit is said to be an extension of mineral zone No. 2 and represents a fissure in the gneiss schist series. The strike is S. 20° E. and dip is 40° N. 80° E., and the planes of schistosity of the country rock dip S. 10° W. The vein is highly siliceous and shows a brecciated character, with a little free gold occurring in some of the joints and fractures of the vein.

MINERAL ZONE NO. 1.

This prospect is similar in many respects to the Mail Pouch and shows a 4-foot brecciated vein, cutting across the schistosity of the gneiss, filled with silicified fragments and cemented by quartz. The vein strikes S. 50° E. and dips northeast.

DOME CITY.

Inclosed in the gneiss and appearing to dip conformably with the planes of schistosity in the Dome City property is a thin layer of calcareous material very much resembling limestone, but which is probably a vein of calcite. This has been replaced in large part by specularite having large flakes one-fourth of an inch across. The vein filling apparently occupies a shear zone in the gneiss schist series, and shows some brecciation. Mr. Osbourne, the owner of the property, states that the vein changes in direction of dip 80 feet down in the shaft from southeast to northeast, this probably representing a fold.

M'CRACKEN LEAD MINE.

LOCATION AND DEVELOPMENT.

The McCracken deposit, located in the Owens mining district, is the only property which the writer had the opportunity of visiting in southern Mohave County, and it has many individual characteristics. According to Mr. H. C. Hodge,[a] this deposit was discovered on August 17, 1874, by Messrs. McCracken and Owens, who retained a part interest in the property after it was incorporated into a San

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[a] Hodge, H. C., Arizona as it is, 1877, pp. 70–73.

Francisco company. Mr. Hodge states that a 10-stamp mill was erected at Greenwood on the Big Sandy River, which place is probably now known as Signal. This is about 12 miles almost due east of the McCracken, the distance by wagon road not being known to the writer. Mr. Patrick Hamilton,[a] writing in 1884, states that an additional 20-stamp mill had been erected, and presumably this was located near the other mill. He also stated that the production, while the property was operated, reached a total of $1,000,000, and that operations had been suspended several years previous to the time of his writing because of the heavy freight charges and the high cost of supplies.

Just how much work has been done on the property since that time the writer is unable to say. A ditch several miles long, for carrying water to the mine, is reported to have been built. This method of conveying water proved a failure in that the ground absorbed the flow. At the present time the mine is in a complete stage of dilapidation, all of the buildings, tramways, and wagon roads having either been torn down or become useless through abandonment

Should the mine be again opened, transportation facilities would be a little more convenient than they have been in the past, although at the present day the nearest railroad point is Swansea, distant 20 miles in an air line, and approximately 40 miles by the present wagon road. Haviland, on the main Santa Fe line, is 30 miles northeast of Castaneta Well in a direct line, and the McCracken mine is 8 miles by wagon road east of the well, so that the distance to Haviland by overland route would probably be between 40 and 45 miles.

The top of McCracken Mountain has an elevation of 3,400 feet, the northeast and southwest slopes of which are decidedly steep, while the northwest and southeast slopes are more gentle and form a long prominent ridge. The surrounding desert has an elevation of between 1,650 and 2,000 feet, so that McCracken Mountain forms a very prominent topographic feature. The workings examined are located on top of and on the southwest side of the upper 500 feet of the mountain, which rises abruptly above the general ridge in the form of a dome.

In 1877 Mr. Hodge[b] stated that the property had been developed by "over 700 feet of shafting and over 1,200 feet of tunnels." He also said that "the deepest shaft is 367 feet, and the shafts and over 1,000 feet of tunnels are in vein matter all the way." If there was this amount of development as early as 1877 the natural conclusion is that nothing has been done on the property since then except in the matter of stoping, two large "glory holes" having been noted which showed excavations in the vein, each measuring at least 20 by

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[a] Hamilton, Patrick, The resources of Arizona, 1884, p. 224.

[b] Hodge, H. C., Arizona as it is, 1877, p. 71.

30 by 70 feet. The upper one of these is on top of the ridge and the other one a short distance below.

The drift just under these large stopes is probably not much over 300 feet long, from which there are numerous short crosscuts. Below this two levels have been run at vertical distances of 100 and 200 feet, respectively. The former is quite short unless caving has so ingeniously blocked the level that a natural face is presented, and the latter is a short crosscut which does not reach the vein. Probably other developments are present, which are inaccessible because of caving. The upper workings seem to have been connected by winzes.

GEOLOGY.

Coarse-grained gray to pink quartz-mica schists, apparently derived from quartz-mica diorites, constitute the main mass of the mountain. These rocks, prior to or at the time of their metamorphism, were intruded by granitic material so that the resulting schists appear as gneiss in many places, and especially so on the northwest continuation of the ridge from McCracken Mountain. Schistose dark-green basic diorite is intercalated with the quartz-mica schists, and the whole series is cut by pinkish pegmatite dikes which show some shearing. Later intrusives of greenish-gray basic diorite cut across the schists, and these are possibly responsible for the mineralization. The mineral constituents of the rocks are all remarkably fresh and show little alteration other than that produced by dynamometamorphism.

Two large fissures form the receptacles for the veins, and these veins run in a north-south direction, parallel to which are one set of joint planes in the rocks, which form a conspicuous feature in the mountain. Two other sets of joints are prominent, one at right angles to the direction of the veins, and the other parallel to the planes of schistosity in the rocks. Innumerable stringers of quartz are present, filling small fissures and fractures in the country rocks.

ORE DEPOSITS.

Two fissure veins, striking north-south and dipping approximately 65° E. form the ore deposits. One of these ledges is very continuous, having been observed for a distance of at least 2,000 feet on the north of McCracken Mountain, and it is reported [a] to have been traced continuously for a distance of 2 miles and to outcrop in places several miles south of this mountain. The width of this vein as observed in the vicinity of the workings varied from 12 to 20 feet. The other vein is not so extensive and was observed near the workings only, the width varying from 6 to 12 feet. Figure 21 shows the outcrop of the veins on top of the mountain and their relation to the quartz-mica schists.

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[a] Hodge, H. C., loc. cit.

The gangue in the vein filling consists principally of carbonates and sulphates with some silicates cementing fragments of schist and quartz. The carbonates are principally calcite and siderite, with which is associated some dolomite, the former being stained by iron and manganese in such a way that many colors result, the pink-stained calcite clearly resembling rhodochrosite. Laboratory tests, however, revealed only a minute quantity of manganese and an appreciable quantity of iron. Some of the highly iron-stained calcite resembles hematite. Quartz is present in large quantities, some of which is amethystine, and crystals of the mineral line many cavities in the vein. Barite is the principal sulphate present, and this occurs in large quantities, usually showing banded structure, which is prevalent in the gangue minerals in this vein. The relative age of the various minerals which form the gangue is not known. One phase of quartz appears to be next to the youngest mineral, for it fills fractures which cut across most of the other minerals and many vugs are lined with it. Calcite is deposited in vugs on top of this quartz.

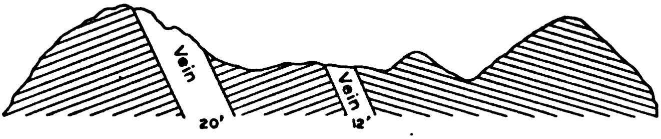

FIGURE 21.—Sketch of top of McCracken Mountain, showing veins.

Formerly deposited quartz is severely fractured and cemented by the carbonates.

The most conspicuous ore mineral is galena, which is reported to be argentiferous. At the time of the writer's visit to this property not a great deal of this was visible, and the natural conclusion is that it occurs in bunches scattered through the vein. Cerusite is probably present in substantial quantities, although its definite identification was not possible. Three assays of vein material in which no metallic sulphides were visible to the unassisted eye gave traces of lead and gold with 2.6, 2.8, and 11.56 ounces of silver to the ton.

Age of the vein and origin of the ores.—That this vein is of comparatively recent origin is almost certain, but it is impossible to state definitely when the disturbances occurred which formed the fissure now occupied by the vein. Probably this represents a part of the Tertiary period of vein formation. As the vein shows evidence of brecciation and subsequent deposition of material, solutions were active during several periods, and it is impossible to state with which, if with any one in particular, the galena was introduced.

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 452

THE
LANDER AND SALT CREEK OIL FIELDS
WYOMING

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E. G. WOODRUFF

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THE LANDER OIL FIELD, WYOMING.

By E. G. Woodruff.

INTRODUCTION.

This report is based chiefly on field work done in July and August, 1909, by a party under the direction of the writer. Dean E. Winchester, chief assistant in the party, has given valuable aid, both in collecting data in the field and preparing it for publication. Other members of the field party were Sam V. Eakin, A. J. Jarrett, and Frank J. Hindera. The writer is indebted to operators and others who are either financially or scientifically interested in the development of the field, especially to E. W. Hainsworth, C. W. Carlisle, N. H. Brown, of Lander, and A. A. Cypert, of Dallas, who furnished information relating to the development, production, and history of the field.

LOCATION AND EXTENT OF THE FIELD.

The Lander oil field is a rectangular area in central Wyoming 39 miles long and from 3 to 11 miles wide, embracing 200 square miles. It lies in Fremont County and extends N. 30° W. from near the middle of T. 31 N., R. 98 W., sixth principal meridian, to T. 2 N., R. 1 W., Wind River meridian. The location and extent of the field are shown on Plate I (in pocket). Lander is the largest town and the principal trading point in the region. It is the terminus of the Wyoming & Northwestern Railway (Chicago & Northwestern system) and the point from which stage lines start northwest and southeast across the field. Hudson is a coal-mining town in the valley of Big Popo Agie River, on the northeastern side of the field. Fort Washakie and Wind River are trading posts in the northwestern part of the area, and Dallas is a post office at a ranch house in the southeastern district. The part of the field northwest of Big Popo Agie River is in the Shoshone Indian Reservation, and development in that area can take place only under lease from the Indians and subject to the regulations of the United States Office of Indian Affairs.

For convenience in description the field is divided into three districts, which coincide in a general way with the three natural and commercial subdivisions of the field. These districts also coincide with the three fields defined by Knight,[a] and are here called the Little Popo Agie district (Popo Agie field of Knight), Big Popo Agie district (Lander field of Knight), and the Little Wind River district (Shoshone field of Knight). The change of names indicated seems advisable, because the field is now commercially known as the Lander field and it seems best to consider the area as one field rather than three, because it is controlled by one continuous structural feature with minor modifications. These lesser modifications fall naturally into three districts, which correspond to the three fields defined by Knight. The names of the districts are derived from small rivers, one of which crosses each district. The streams are sufficiently large to be familiar to the inhabitants of the region, and the development work in the field, except possibly that done at one or two places, is included in their valleys.

The Little Popo Agie district occupies the entire southeastern part of the field and extends northwestward to a line midway between Big and Little Popo Agie Rivers. Practically all the development work in the field has been done in this area, and a pipe line is now completed from the oil wells near Dallas to the railroad at Wyopa.

The Big Popo Agie district comprises the central part of the field and extends from the Little Popo Agie district to a line midway between Big Popo Agie and Little Wind River. It is crossed by the railroad and contains the terminus of the pipe line from the Little Popo Agie district. Until the summer of 1909 the only well in the central part of the field was in Big Popo Agie Valley near the river, but early in that summer a well was located on the crest of the anticline in the western part of the district. It was not finished when the area was examined, but subsequent reports from the operators state that oil was found at a depth of 250 feet. This well is close to the site of the Washakie oil spring, which has long been famous because of the medicinal properties of the oil.

The Little Wind River district includes the northwestern part of the field. It contains the hot spring near Fort Washakie and the tar spring to the north, across the river. One abandoned well is located at the site of the tar spring and another well was being drilled in the valley of Sage Creek at the time the field was examined.

TOPOGRAPHY.

Viewed as a whole the Lander oil field consists of a central highly dissected ridge with moderately trenched, slightly undulating plains on either side. It is crossed obliquely in the southeastern district by Little Popo Agie River, in the central district by Big Popo Agie River, and in the northwestern district by Little Wind River, all of which rise high in the Wind River Mountains, flow down the slopes in deep-cut canyons, and cross the field in their course to Wind River, the trunk stream of the region. Besides these streams, Twin Creek enters the southeastern district from the east and after crossing the axis of the field in a narrow canyon turns along the strike of the beds and flows northwestward to Little Popo Agie River. Similarly Sage Creek enters from the west near the northwestern end of the field, crosses the beds on that side of the anticline in a diagonal course, and flows southeastward to Little Wind River.

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[a] Knight, W. C., The geology of the Popo Agie, Lander, and Shoshone fields: Bull. Univ. 'oming School of Mines, Petroleum series No. 2, Laramie, Wyo., January, 1897.

The topographic expression of the field is believed to have resulted from the erosion of a plain composed of loose material that once covered the area at a much higher altitude than the present surface and sloped northwestward from the mountains toward the interior of the Wind River Basin. Streams whose courses approximately coincide with the present ones rose on the high mountains and flowed northeastward across this field. They gradually removed the surface covering of loose material and became superimposed upon the lower harder beds. At this stage the harder rocks which had been folded previously in the central part of the area resisted erosion more than the softer beds on both sides and in consequence a ridge was developed on the hard rocks along the axis of the field and plains were formed on both sides. Furthermore, in the shale beds which lay on both sides of the hard core, erosion is progressing rapidly at this time; consequently the main streams occupy channels in gorges, or have only small flood plains, and the lateral branches are in trenches. As a result of these conditions the central part of the field is rough. It consists of many sharp-crested steep-sided ridges carved by numerous ravines. The plains on either side possess an undulating surface intersected here and there by narrow steep-sided gorges. Roads and various culture features are controlled by this topography and directed along two lines. The first line extends in the direction of the axis of the fold, because the strike ridges prevent easy passage across the fold, except where it has been cut by the main streams. The second direction in which progress is possible is along the valleys of the larger streams transverse to the ridges. (See Pl. I, in pocket.)

The topography and the culture shown on the map were prepared from data collected by the field party. The survey was accomplished by means of the plane table, telescopic alidade, and stadia rod. Vertical control is based primarily on United States Geological Survey bench marks, one line of which extends along Little Wind River and another from Lander to Dallas, and also on the profile of the Wyoming & Northwestern Railway, which crosses the central district. From these base lines altitudes were determined instrumentally at short intervals and the topography was sketched.

GEOLOGY.

STRATIGRAPHY.

GENERAL FEATURES.

The strata exposed at the surface in this field belong to the Triassic (?), Jurassic, Cretaceous, Tertiary, and Quaternary systems. Below the Triassic (?) are rocks of Permian (?) and Pennsylvanian age, which do not outcrop in the field but are exposed on the slope of Wind River Mountains and dip under the field. They are entered by some of the oil wells and are believed to be the source of most, if not all, of the oil, and are therefore included in the discussion of the stratigraphy of the field.

The following table shows the relations of these formations:

Geologic formations in the Lander oil field.

Era.	System.	Series.	Group.	Formation.	Character.	Thickness in feet.
Cenozoic.	Quaternary.	Recent.			Alluvium.	
	Tertiary.	Eocene.		Wind River formation.	Sandy shale, shaly sandstone, and local beds of conglomerate.	Only the lower part exposed.
		Unconformity.				
Mesozoic.	Cretaceous.	Upper Cretaceous.	Montana.	Mesaverde formation.	Massive light-buff sandstone and sandy shale.	Less than 200 feet exposed.
			Colorado.	Mancos shale.	Drab sandy shale merging upward into moderately rusty very sandy shale.	6,110.
				Dakota sandstone.	Massive ferruginous sandstone.	20 to 56.
		Lower Cretaceous (?).			Shale, sandy, and sandstone in both massive and shaly beds and beds of conglomerate locally developed.	400 to 410.
	Jurassic (?).			Morrison formation.	Variegated sandy shale and conglomerate composed of water-worn pebbles.	236 to 242.
	Jurassic.			Sundance formation.	Olive-green fossiliferous limestone and shale.	347 to 350.
	Triassic (?).			Chugwater formation ("Red Beds").	Sandy shale and massive sandstone.	1,500.
Paleozoic.	Carboniferous.	Pennsylvanian, with Permian (?) at top.		Embar formation.	Massive and shaly limestone (locally containing chert), shale, and sandstone.	344.

A columnar section of the formations is presented in figure 1. The small type along the margin of the section shows the locality where each part was measured. The Embar and the lower members of

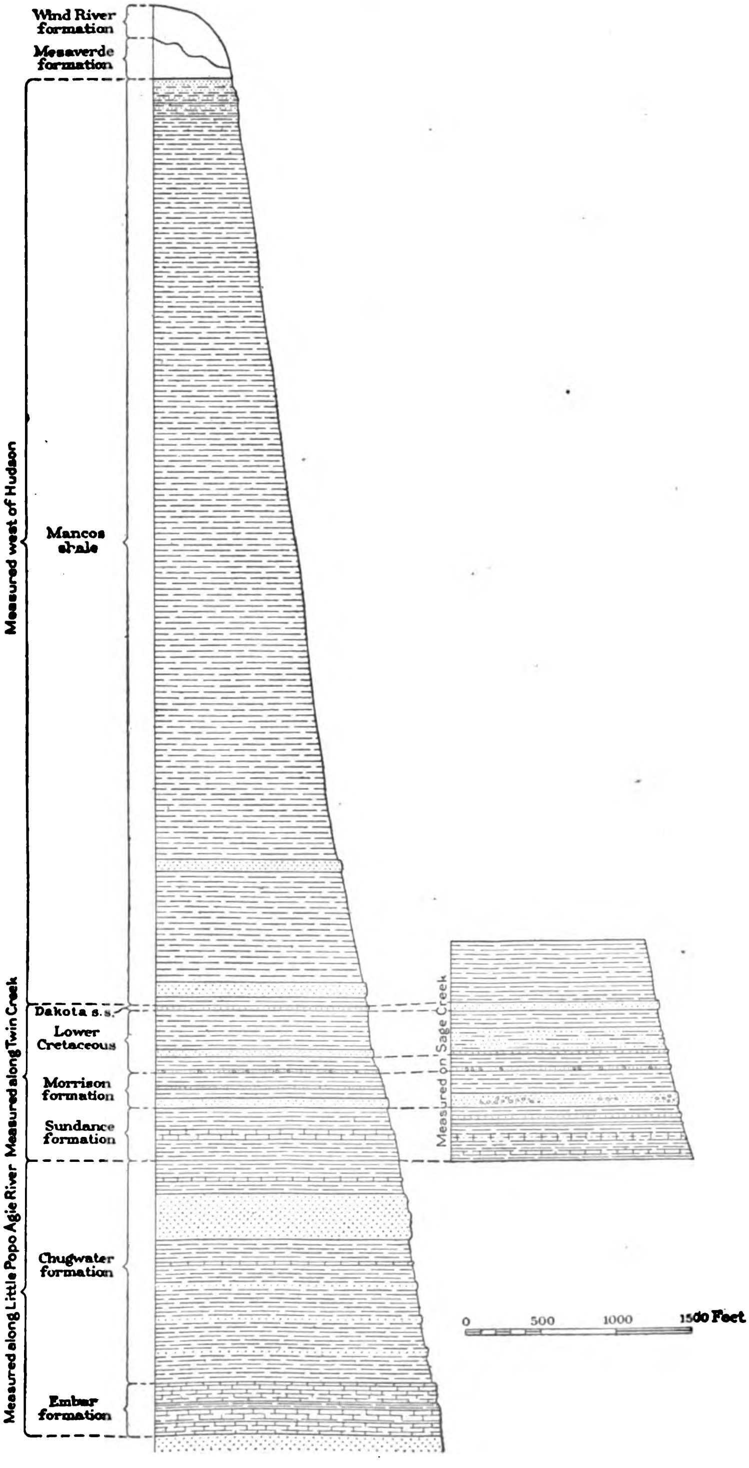

FIGURE 1.—Columnar section showing the geologic formations in the Lander oil field.

the Chugwater formation were not exposed in the field, and were therefore measured along the canyon of Little Popo Agie River, where good exposures were obtained a few miles southwest of Dallas post office. The thickness of the Sundance, Morrison, Lower Cretaceous (?), and Dakota formations was determined along Sage Creek in the northwestern district and along Twin Creek in the southeastern district. The Mancos, Mesaverde, and Wind River formations were measured in the central district west of Big Popo Agie River.

DETAILED DESCRIPTIONS OF THE FORMATIONS.

EMBAR FORMATION.

Embar is the name applied to the lowest group of beds considered in this report. Lower Paleozoic formations are exposed on the side of the Wind River Mountains adjacent to the area and are believed to pass under the field and to be involved in the structure, but since they bear no direct relation to the oil they are not discussed here. Although the Embar formation is not exposed in the Lander oil field it is believed to be the source of some of the oil, and as some of the wells penetrate it, it will be described.

About half of the Embar formation consists of limestone, most of it massive and crystalline, but certain members of this half are shaly and cherty; the other half of the formation is shale. Two members consist of very shaly sandstone containing a large percentage of lime and some bituminous matter which comes to the surface in oil seeps. Pieces of this rock contain small cavities filled with oil or lined with bitumen. The survey made was insufficient to show the continuity, character, and extent of the two oil-bearing beds, but it was determined that both of them are highly fossiliferous. The upper bed is 4½ to 5 feet thick, the lower bed is 2 feet thick, and the two are separated by strata measuring in thickness 215 feet. These sandstones and adjoining limestones, where they have been folded into favorable structural shape for the accumulation of oil, form natural reservoirs which are to be sought in drilling in this region. Oil may locally accumulate at higher horizons, as at the oil springs near wells Nos. 1 and 2, Little Popo Agie district, but generally it is to be sought near the top of the Embar. The following section was measured in the canyon of Little Popo Agie River 6 miles southwest of Dallas:

Section of Embar formation in canyon of Little Popo Agie River 6 miles southwest of Dallas.

	Feet.
Limestone, shaly and tan-colored; sandy at top; lies immediately below red shale at the base of the Chugwater formation; contains some fossils (collection No. 121, listed below, was obtained from this member)	18

	Feet.
Limestone, massive, crystalline, slightly cherty and with distinct major joints. Contains fossils (collection No. 122)	23
Limestone, concretionary, cherty, slightly shaly	45
Shale, drab, sandy	40
Sandstone, bituminous; the upper oil sand. Not well exposed, but best measurement obtainable shows it to be about 5 feet and certainly not more than 10 feet thick. Yielded fossil lot No. 123	5
Limestone, shaly, crystalline	5
Shale (?). Surface covered by talus, but underlying rock is probably shale	24
Shale; small blotches of oil on surface, as if globules had oozed from the rock since its exposure; probably some oil has seeped into this from below	21
Limestone, massive, impure, with well-developed major joint; lower part concealed	73
Limestone; contains occasional thin, shaly limestone layers, one of them (oil sand No. 2) 2 feet thick, sandy and very fossiliferous	90
	344

The age of the Embar is determined from fossils collected in it and identified by G. H. Girty, as follows:

Fossils of the Embar formation.

Lot 121.

Deltopecten occidentalis?
Myalina aff. perattenuata.
Myalina aff. swallowi.
Mytilus? sp.
Sedgwickia? several sp.
Allerisma sp.
Bakewellia? several sp.
Bellerophon aff. crassus.
Gasteropoda indet.

Lot 123.

Spirifer? sp.
Leda sp.
Nucula aff. levatiformis.
Pleurophorus? sp.
Small indeterminable gastropods.
Fish plate.

Lot 151.

Lingulidiscina utahensis?

Regarding the geologic age of these fossils Dr. Girty writes:

> Lot 121 very probably belongs to the fauna which occurs in the "Permo-Carboniferous" (Ankareh, Thaynes, and Woodside formations) of the Wasatch Mountains section in Utah, as defined by the geologists of the Fortieth Parallel Survey. This fauna is widely distributed in Idaho, Wyoming, and Utah. Its geologic age is at present in doubt, having been variously determined as "Permo-Carboniferous," Permian, and Triassic.
>
> The faunas of the two other lots are hardly diagnostic enough for a satisfactory correlation, but 151 is almost certainly Paleozoic, and I would tentatively place both collections at a lower horizon than 121.

From the Embar Mr. Darton has obtained *Spiriferina pulchra*, a Pennsylvanian species, and one which seems to be characteristic of the Park City formation of Utah and Idaho. The data at hand therefore seem to indicate that the Embar formation as at present limited includes two faunas very different from each other and of different geologic ages. The upper is represented by lot 121, listed above, and the lower by the two other lots collected by Mr. Woodruff and by the one collected by Mr. Darton, which contains *Spiriferina pulchra* and on the strength of which the whole formation was originally referred to the Pennsylvanian.

The formation is exposed in an almost continuous belt along the Wind River Mountains and undoubtedly underlies the oil field and conforms to the general anticlinal structure. Although it comes to the surface at no point, it lies so near the surface that some of the wells penetrate it. In the Little Popo Agie district the formation is reached at a depth of about 700 feet, and in the Little Wind River district at 1,150 feet.

CHUGWATER FORMATION.

The Chugwater ("Red Beds") is the most easily recognizable formation in the region, because it comprises brick-red sandy shale and sandstone nearly 1,500 feet thick. Since there is a very noticeable difference in the thickness of the formation as determined by the writer and as given by Knight,[a] who states that it is nearly 1,000 feet, the writer feels justified in stating the method used by him in determining its measurement. The base of the Jurassic was located in a bank on the west side of Little Popo Agie River, from which point a stadia traverse was run across the strike of the Chugwater. Relative elevations were carefully determined and dip and strike measurements were made at frequent intervals. The thickness of the beds was computed from these data and further checked by the known thickness of the beds exposed along Little Popo Agie River increased by the thickness determined from the logs of wells. A structure section of the district prepared by Knight shows that all the Chugwater has been removed and that the Embar is covered by alluvium only, whereas the records of wells show that the base of the Chugwater formation is 700 feet below the surface.

About three-fourths of the formation is shale and one-fourth is intercalated sandstone. The formation also contains some limestone and thin discontinuous lenses of gypsum. Some parts of both the shale and sandstone are massive and hard; others are loose and soft. A thin bed of oolitic sandstone occurs 220 feet below the top and a bed of dolomite 4½ feet thick lies 475 feet lower. The following section of this formation was measured along Little Popo Agie River southwest of Dallas.

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[a] Knight, W. C., Petroleum of the Shoshone anticlinal: Bull. Univ. Wyoming School of Mines, Petroleum series, No. 2, Laramie, Wyo., January, 1897.

Section of Chugwater formation along Little Popo Agie River southwest of Dallas.

	Ft.	in.
Shale, red	123	
Shale, sandy, gray	6	6
Limestone, gray, dolomitic, massive, breaking into angular blocks	9	
Shale, sandy, red, with occasional thin shaly sandstone layer	8	6
Sandstone, massive, pink, forming ridge	309	
Shale, sandy, dark red	158	6
Limestone, massive, angular, gray, dolomitic, breaking into angular blocks. Locally this bed is thin bedded and irregular, as if deposited from hot springs	4	6
Shale, sandy, dark red. Intercalated in this shale at intervals there are zones 10 to 20 feet thick, of very shaly thin-bedded sandstone	802	
	1,421	

The formation is remarkable for the scarcity of its organic remains. No well-preserved shells or remnants of vegetable life were found in it. S. W. Williston[a] reports finding the bones of Triassic reptiles in beds 40 to 80 feet thick and 200 feet below the top of the formation. By the identification of species in these collections the Chugwater is referred provisionally to the Triassic. No stratigraphic unconformity was observed between the Chugwater and the Embar below or between the Chugwater and the Jurassic above it.

The exposed portion of the formation is distributed into four separate areas, one of which forms a nucleus for the northwestern district, another for the central, and two for the southeastern district. The areal distribution of this formation is shown on Plate I.

SUNDANCE FORMATION.

The name Sundance, like several others used in this report, has been applied to this formation in the Black Hills of South Dakota and in the Bighorn Mountains and Bighorn Basin, Wyoming. The correlation between this field and those in which the formation has been recognized is based on the occurrence of identical fossils and on similarity of lithological character and stratigraphic position. The Sundance formation is of marine origin and of Jurassic age. It comprises olive-green fossiliferous limestone and sandy shale, which is olive green in the upper part of the formation, but tan in the lower part. The formation is easily recognized by its position immediately above the red beds of the Chugwater, by its green color, and by the abundance of fossils found in both the limestone and shale. The formation, as shown by the following sections, is 350 feet thick along Sage Creek, in the Little Wind River district, and only a few feet less along Twin Creek, near the southeastern limit of the field.

---

[a] Williston, S. W., Notice of some new reptiles from the Upper Trias of Wyoming, Univ. Chicago Press, 1904.

Section of Sundance formation along Sage Creek.

	Ft.	In.
Shale, sandy, olive green	46	
Sandstone, shaly, light tan, locally massive	25	
Shale, sandy, light tan generally, but at some places slightly olive green	45	
Sandstone, shaly, tan colored	5	
Shale, sandy, tan colored	40	
Sandstone, shaly, locally becoming compact	3	
Shale, sandy, tan colored	15	4
Limestone, highly fossiliferous		8
Shale, sandy, tan colored	3	
Shale, sandy, fine grained, tan colored, merging into a 3-foot bed of very sandy, shaly, fossiliferous limestone at the top	30	
Limestone, highly fossiliferous. This bed is regularly jointed and weathers into pieces from 4 to 10 inches square	1	
Shale, sandy, tan colored. In the upper 10 feet there is an abundance of *Belemnites*	87	
Limestone, shaly, highly fossiliferous	2	
Shale, slightly sandy, yellowish tan; no fossils found	43	4
Limestone, shaly		8
Shale, tan	3	
	350	

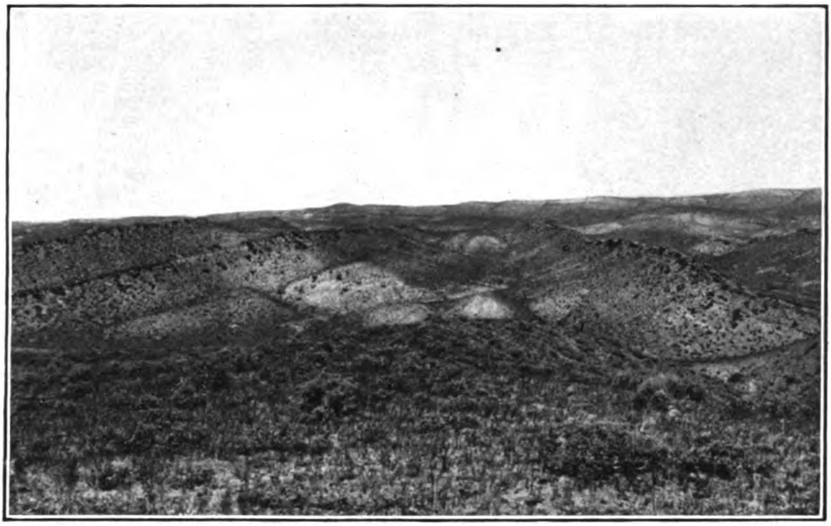
Section of Sundance formation along Twin Creek.

	Feet.
Shale, sandy, pink, gray, and maroon	149
Limestone, shaly, thin bedded, highly fossiliferous	52
Shale, slightly sandy, green	146
	347

The Sundance formation outcrops in a narrow zone bordering the Chugwater formation in each of the four areas where that formation is exposed and occurs in much larger tracts where it arches over the crest of the anticline. (See Pl. I.) The Sundance is exposed on the flanks of the anticline in each district where the crest has been eroded and arches over the summit where erosion has not progressed so far. Plate II, *A* and *B*, shows the structure of this formation where it makes a sharp fold along Sage Creek in the northwestern part of Little Wind River district.

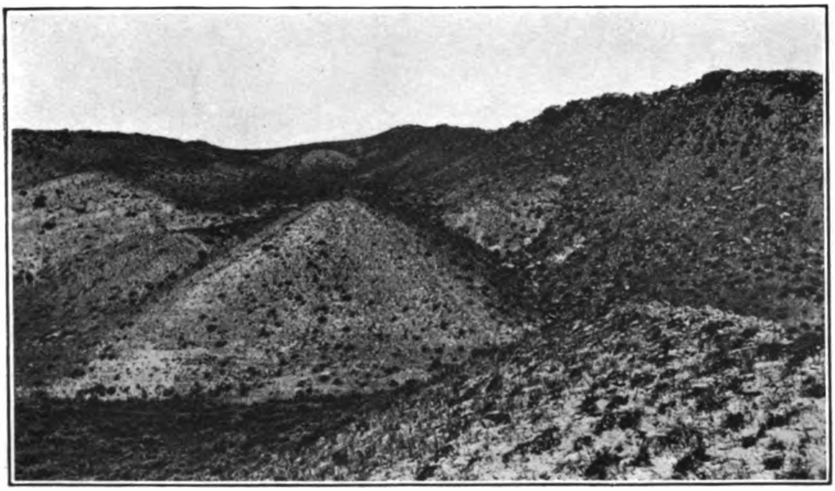
MORRISON FORMATION.

The Morrison formation embraces fresh-water sandstone, sandy shale, and conglomerate beds. The shale consists of intercalated beds of maroon, brick red, gray, tan, and green colors, none of which were found to be continuous beyond a short distance. The conglom-



A. GENERAL VIEW OF BEDS FORMING THE CREST OF THE ANTICLINE IN T. 1 N., R. 1 W., WIND RIVER MERIDIAN.

The top of the arch shown near the middle of the picture is in the Sundance formation and the ridges just to the right and left are composed of Lower Cretaceous sandstone. Along the skyline in the background is the Mowry shale member.



B. VIEW OF BEDS FORMING THE CREST OF THE ANTICLINE IN SEC. 4, T. 1 N., R. 1 W., WIND RIVER MERIDIAN.

The arch in the center is composed of Jurassic beds. The ridge to the right is formed of Lower Cretaceous sandstone.

erate comprises beds of small, well-rounded quartz pebbles, loosely cemented. The sandstone occurs in both massive and shaly beds. The following sections show the character of this formation. (See also fig. 1.) One section was measured near Sage Creek, in the Little Wind River district, and the other on Twin Creek, in the Little Popo Agie district.

Section of Morrison formation along Sage Creek.

	Feet.
Shale, massive, banded, maroon at the top and brick red and lighter in color below; about equal parts of each member	154
Sandstone, gray and tan in color, weathering tan, generally coarse-grained and locally becoming a conglomerate. The upper part of this member weathers to a bright red	88
	242

Section of Morrison formation along Twin Creek.

	Feet.
Shale, soft, sandy, subdued colors, maroon, pink, and gray	86
Sandstone, massive, gray in the lower part and slightly shaly in the upper part	6
Shale, sandy, light green	4
Sandstone, massive, gray	16
Shale, sandy, gray in the upper third, pink in the middle third, and light pink in the lower third	63
Sandstone, massive, gray, forming cliff	61
	236

The type locality of the Morrison is in Colorado, but the name has been applied to the formation in this region by Darton[a] who based the correlation on lithologic character. No fossils were found in this formation, but it occupies the stratigraphic position at which the Morrison is found in adjacent fields and lithologically is not unlike the formation as recognized and described by Darton[b] in the Bighorn Mountains and by Fisher[c] in the Bighorn Basin. Paleontologists do not agree as to the age of the Morrison formation. Some have referred it to the Jurassic, but others consider it Lower Cretaceous. In this report it is referred provisionally to the Jurassic, though a final decision can not be made at this time. The Morrison outcrops in a zone just outside of and parallel to the Sundance formation in each of the three districts. Besides these narrow belts there is a larger area of this formation adjacent to the strike fault in the Little Popo Agie district. (See Pl. I, in pocket.)

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[a] Darton, N. H., Paleozoic and Mesozoic of central Wyoming: Bull. Geol. Soc. America, vol. 19, 1908, p. 443.

[b] Darton, N. H., Geology of the Bighorn Mountains: Prof. Paper U. S. Geol. Survey No. 51, 1906, p. 47.

[c] Fisher, C. A., Geology and water resources of the Bighorn Basin, Wyoming: Prof. Paper U. S. Geol. Survey No. 53, pp. 25, 41.

LOWER CRETACEOUS ROCKS.

The lower part of the Cretaceous, underlying the Dakota sandstone, consists of sandy shale and sandstone. The basal member is a massive gray coarse-grained cross-bedded sandstone, which locally becomes conglomeratic. The conglomerate is formed mostly of water-worn gray-quartz pebbles, some of which are as large as one-third inch in diameter. The upper member is a soft sandy tan-colored shale. The following sections present the character of the beds:

Section of the lowest beds in the Cretaceous along Twin Creek, in Little Popo Agie district.

	Feet.
Shale, soft, sandy, tan in the lower part, drab in the upper part; weathers to form slope	267
Sandstone, slightly shaly, rusty, weathers to form cliffs. Contains many impressions of wood and stems	44
Shale, soft, sandy, gray in the lower part with brick red in middle and gray above	88
Sandstone, massive, gray, coarse grained, cross-bedded, and containing conglomeratic layers. Beds from 1 to 6 inches thick near the base. Two miles farther east this member is a gray conglomerate with small, well-rounded pebbles of chert, both gray and black	9
	408

Section of the lowest beds in the Cretaceous along Sage Creek, in Little Wind River district.

	Feet.
Shale, drab, fissile, with a thick bed of black carbonaceous shale near the middle	123
Sandstone, shaly, rusty, merging into rusty colored sandy shale at the top	158
Sandstone, massive, rusty, but weathering gray in places. This sandstone is hard and weathers into a distinct shoulder. Some imperfect bivalves (*Unio?*) were found in it	12
Shale, sandy, maroon colored, merging into gray at the top	93
Sandstone, massive, gray, weathering gray. Locally this sandstone becomes a gray conglomerate formed of well-rounded pebbles of quartz, generally about one-third inch in greatest diameter, and rarely exceeding 1 inch	20
	406

The age of these beds has not been clearly determined. The study of the stratigraphy in the field indicates that the lithologic unit comprising the Morrison formation terminates upward at the bottom of the gray sandstone and conglomerate beds that form the basal member of the Cretaceous in the above sections. It is also believed that the beds between the top of the Morrison and the base of the Dakota sandstone were deposited under similar conditions and are therefore a unit of deposition. The opinion that the lower part of the Cretaceous is of marine origin is based on data furnished by T. W. Stanton, who examined the beds at several points and collected fossils from the upper member. Dr. Stanton submits the following statement concerning the fossils:

> The interesting faunule of marine shells, concerning which I am not ready to express a decided opinion, was found at a number of places a short distance beneath the Dakota sandstone, or at least beneath a sandstone which, west of Lander, yielded a Dakota flora. From its stratigraphic position and its general characteristics this faunule ought to be Lower Cretaceous, but I have not been able to make specific identifications of any forms characteristic of the Lower Cretaceous or the Comanche series.

This group of beds was referred by Knight [a] to the Jurassic without any specific separation, and by Darton [b] to the Morrison. The evidence outlined above, produced by the more detailed work recently undertaken, seems to show that these beds are distinct from the Morrison, which lies below them, and that they are Lower Cretaceous in age, and not a part of the Dakota, which lies above, and is Upper Cretaceous. It is believed that they form a distinct stratigraphic unit, but the evidence at hand is inconclusive both as to the limits and age of the strata. Therefore the proposal of a name for them is deferred until more conclusive evidence can be obtained, in order to avoid the confusion which may arise from the inaccurate definition of a formation.

DAKOTA SANDSTONE.

The Dakota sandstone of this area has been described by Eldridge,[c] Knight,[a] and Darton,[d] all of whom properly correlated it with the Dakota of the type locality. Mr. Darton, however, has called this formation the Cloverly sandstone,[e] but the name Cloverly had been used previously by him for a tripartite group of beds composed of "coarse, massive, buff sandstone below, with light-colored shales and some sandstone above," believed to include the "Dakota, Fuson, and Lakota.[f] To the writer it seems inconsistent to apply a name to a group of beds at one place and to only one member of the group in an adjacent area where the strata are similar, and it therefore seems best either to broaden the application of the term in the Lander field to include the group (consisting of the Dakota sandstone and the underlying Lower Cretaceous (?) shale and sandstone) or to reject the term entirely. The latter course is pursued, because the bed in this area to which Mr. Darton applied the name Cloverly sandstone is shown to be Dakota sandstone by the list of fossil plants given below, and because earlier writers properly termed the bed Dakota. The formation consists of a massive rusty sandstone nearly 60 feet thick in the northwestern part of the field but about one-third of that amount in the southeastern part. The following sections present the thickness of the Dakota:

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[a] Bull. Univ. Wyoming School of Mines, Petroleum series, No. 2, 1897, p. 9.

[b] Bull. Geol. Soc. America, vol. 19, 1908, p. 442.

[c] Eldridge, G. H., A geological reconnaissance in northwest Wyoming: Bull. U. S. Geol. Survey No. 119, 1894, p. 22.

[d] Op. cit., p. 448.

[e] Idem, p. 447.

[f] Prof. Paper U. S. Geol. Survey No. 51, 1906, pp. 14, 50.

Dakota sandstone on Twin Creek, in Little Popo Agie district.

	Feet.
Sandstone, massive, rusty; forms one of the highest ridges in the region	20

Dakota sandstone on Sage Creek in Little Wind River district.

	Feet.
Sandstone, massive gray, weathers gray except in the upper part, where it weathers rusty	56

The age of the formation is determined from the following fossils collected 2 miles west of Lander and identified by F. H. Knowlton:

Fossil plants collected from the Dakota sandstone.

No. 1455 (5500). 2 miles W. of Lander, Wyo.

Hymenophyllum cretaceum Lesq.
Sassafras acutilobum Lesq.
Sassafras mirabile Lesq.
Andromeda pfaffiana Heer.
Magnolia pseudo-acuminata Lesq.
Laurus proteæfolia Lesq.
Rhus powelliana? Lesq.
Salix proteæfolia Lesq.
Platanus affinis Lesq.
Myrica aspera? Lesq.
Myrica longa Heer.
Hedera sp.?
Aralia saportana Lesq., or new.
Celastrophyllum ensifolium Lesq.
Populus? cordifolia Newb.

Dr. Knowlton remarks as follows concerning these specimens:

> The specimens are much broken, but doubtless with very close study two or three other species might be determined with more or less certainty. As it is there is an ample number to prove its Dakota age.

The Dakota and the Lower Cretaceous were not mapped separately in the field; therefore both formations are shown by the same color on the map (Pl. I).

MANCOS SHALE.

The Mancos comprises a mass of sandy shale and sandstone more than 6,000 feet thick, and is therefore the thickest formation in the field. One member, called the Mowry shale member by Darton,[a] consists of hard, drab, thin-bedded fine-grained sandy shale, which weathers gray. It is believed that the change of color on weathering is due to the loss of carbonaceous material, which the shale includes. The shale contains abundant impressions of fish scales but no parts of the skeleton were found. This member is near the base of the formation, and weathers into high, moderately steep ridges, which form one of the most persistent topographic features of the field. The fish scales and carbonaceous matter in this member have attracted the attention of investigators seeking the primary source of the oil in this and other fields in Wyoming. Some have suggested that the innumerable scales indicate a prolific type of fish, whose remains were included in the shale and contributed the carbonaceous matter in the form of fish oil, which has since been segregated in part and forms the oil pools occasionally found.

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[a] Darton, N. H., Geology of the Bighorn Mountains: Prof. Paper U. S. Geol. Survey No. 51, 1906, p. 53.

The great mass of sandy shale in the Mancos is loose and easily broken up; hence most of the area occupied by that formation is reduced to broad, open flats. There are, however, small areas where erosion is progressing rapidly, forming badlands or uneven surfaces trenched by narrow, steep-sided gullies. The age of the lower part of this formation is definitely fixed by the abundance of fossils found in it, but the time in which the middle and upper parts were deposited is less certain. No evidence has been obtained concerning the middle part, but since there is continuous deposition from the known Colorado the middle part of the formation is provisionally assigned to that group. The upper part, likewise, seems to indicate continuous deposition, but fossils collected from it and identified by Dr. Stanton are referred to the Montana rather than the Colorado group. The evidence at hand is therefore insufficient to indicate the line of separation between the two groups. It is believed that there is a gradual transition from the Colorado to the Montana group, and that the deposition of the upper member of the Mancos began in Colorado time and extended without distinct interruption into the Montana. This is a condition similar to that at the type locality of the Mancos, where deposition was continuous from the Colorado to the Montana, and there is no striking lithologic change at the boundary between the two groups. The following is a list of invertebrate fossils collected near the top of the member about 1 mile northwest of Hudson:

Anomia sp.
Modiola regularis White.
Corbula undifera Meek.
Corbula subtrigonalis M. and H.
Siliqua? sp.
Melania insculpta Meek.

Because it is impossible in the field to separate this shale into lithologic units, the entire mass is included in the Mancos, which extends upward to the base of the Mesaverde formation.

The following section of the Mancos was measured north of Big Popo Agie River, west of Hudson:

Section of Mancos shale west of Hudson, Wyo.

	Feet.
Shale, light drab, with occasional brown sandstone beds up to 12 inches thick	150
Shale and sandstone, shale predominating	90
Shale, gray	4,900
Sandstone, light gray, and shale, soft, light drab	80
Shale, thin bedded, light gray, with fish scales (Mowry)	730
Sandstone, heavy, gray	100
Shale, sandy, soft; in color light	60
	6,110

Areally the Mancos is the most widely distributed formation in the field. It arches over the axis of the anticline at both ends of the central and northwestern districts and forms broad flats on both sides of the main uplift. The Mancos conforms to the general anticlinal structure of the field. It lies on the flanks of the uplift where erosion has removed it from the crest and revealed the lower beds, and it arches over the crest at both ends of each of the three districts except at the southeastern end of the field, where terrace gravel conceals all the pre-Quaternary rocks. On the southwestern side of the anticline the Mancos dips into the syncline and then rises and is exposed on the flanks of the Wind River Mountains. The northeast limb of the anticline becomes a part of the monocline which extends from the oil field toward the interior of the basin.

For years oil has been seeping from this formation at the Washakie oil spring, in the northwestern part of the Big Popo Agie district. During the present survey of that part of the field a well was being drilled near the site of the oil spring, and it was reported that oil had been found in this well (locally known as the Plunkett well) at a depth of 250 feet, and at a point which is stratigraphically in the Mowry shale.

MESAVERDE FORMATION.

The Mesaverde formation comprises massive light tan-colored sandstone and sandy shale, deposited apparently conformably to the Mancos. The basal member is characterized by massive sandstone and intercalated shale beds containing lenses of coal. This formation has been determined to be the Mesaverde from invertebrate fossils collected by the writer and identified by T. W. Stanton; previously, however, it had been considered as Laramie.[a]

WIND RIVER FORMATION.

The Wind River formation is composed of sandstone and sandy shale in about equal parts. The sandstone members are lenticular, reaching in places a thickness of 20 feet and a lateral extent of 1 mile, and are composed of subangular grains of quartz, feldspar, and various kinds of igneous rocks. The shale consists of intercalated gray, pink, and red members. Locally a conglomerate containing coarse, moderately well rounded pebbles is the basal member of the formation. The Wind River formation rests unconformably upon the strata below and has been slightly tilted from the horizontal. It was deposited in Eocene time but subsequent to the deformation which warped the Fort Union beds, as determined by the evidence of fossil plants identified by F. H. Knowlton. The Fort Union is not exposed in this field because, if it was deposited, it has either been removed by erosion or is concealed beneath the Wind River formation. Areally, the Wind River formation is distributed along the northeastern border of the field and in an isolated outlier several square miles in extent lying between Little Wind River and Big Popo Agie River.

STRUCTURE.

GENERAL FEATURES.

The structural province in which this field lies comprises very broad synclinal basins bordered by relatively high narrow mountain ranges with small steep-sided, slightly elevated anticlines that are exposed about the edges of the basins in a zone between the basins proper and the mountains. If the strata in the interior of the basins are folded, the folds are concealed beneath beds which were deposited subsequent to the major structural movements in the province. It seems probable that there are folds in the interior and possibly some of them contain oil, but they can be found only by drilling.

The Wind River basin is typical of the large synclines and the Wind River Mountains of the high anticlines, and the field here discussed is embraced in the zone of secondary folds exposed on the border of the basin. The minor folds are asymmetrical, the beds near the Wind River Mountains dipping steeply, but those on the opposite side of the field lying more nearly level.

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[a] Eldridge, G. H., A geological reconnaissance in northwest Wyoming; Bull. U. S. Geol. Survey No. 119, 1894, p. 24.

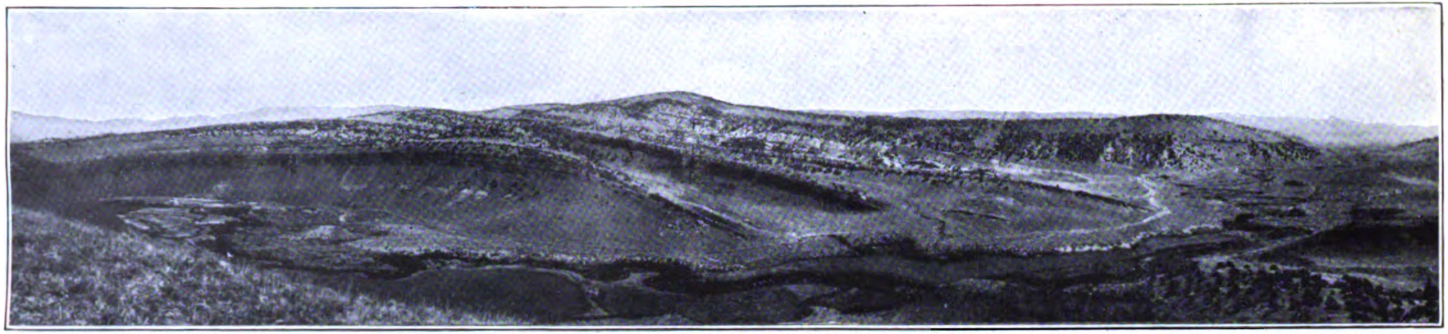
The crest of the anticline is not a horizontal line, but undulates gently, a rise corresponding to each district and a depression lying between. The general structure is further complicated by faults in the southern district and by a spur from the main fold in the Little Wind River district. Locally, the rocks are sharply folded and may have been faulted, but there is no direct evidence of breaks except at places where faults are shown on Plate I. Fractures, however, may be indicated by oil springs which appear at three points along the anticline and by a large hot spring which occurs at another place near the crest of the uplift.

The structure of the field is represented by the structural contours on the map forming Plate I, which shows the position of the base of the Chugwater formation with regard to sea level. The contour interval is 500 feet, and the figures placed along the lines show the distance of each contour above sea level. If a figure is preceded by the plus sign (+), it indicates that the base of the Chugwater is the given number of feet above sea level at all points along that line, and if preceded by minus sign (—), that it is below sea level. Since the surface contours are also based on sea level, the depth of the base of the Chugwater below any point is the difference between the altitude of the two contour lines.

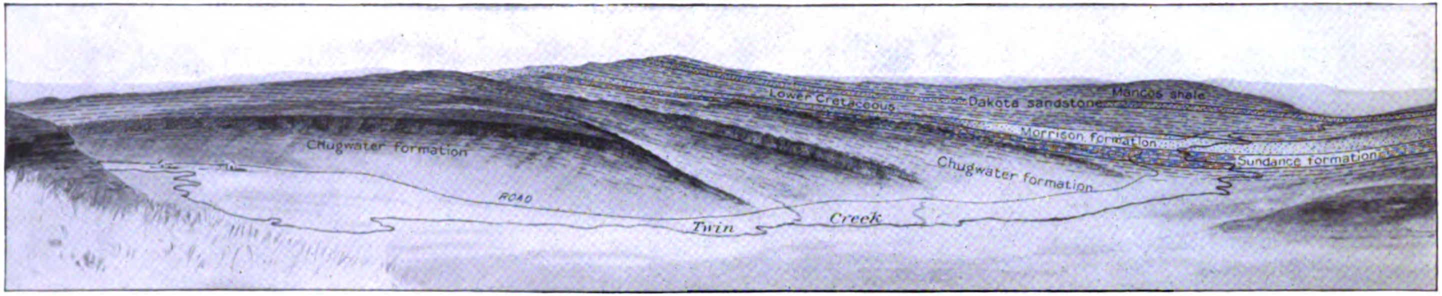
ARTESIAN CONDITIONS.

In this oil field artesian flows of water in drill holes interfere with the drilling to a considerable extent, and sometimes even stop the work; hence a brief discussion of the artesian conditions is presented. Flows of water under pressure may be expected in wells at almost any depth.

Although the oil field itself is an anticline artesian conditions within it are almost ideal because the beds involved are exposed beyond a neighboring syncline on the flank of the Wind River Mountain high above the oil district, thus producing excellent conditions for the absorption of water by the porous strata and its accumulation under pressure. Some of the beds are poorly cemented sandstones which absorb and transmit water readily, and the bedding planes of others are suitable conductors. The high portions of the Wind River Range are covered by snow throughout the year. The melting of this snow and the rainfall in the same area together give a rather constant supply of water to the exposed edges of the porous beds. Thus the structure, character of the beds, and the constant supply of water favor artesian flows.



A. VIEW OF ANTICLINE IN LITTLE POPO AGIE DISTRICT, LANDER OIL FIELD, LOOKING NORTHWEST ACROSS TWIN CREEK.



B. DIAGRAM SHOWING STRUCTURE AND STRATIGRAPHY OF ANTICLINE IN LITTLE POPO AGIE DISTRICT.

DETAILS OF STRUCTURE.

LITTLE POPO AGIE DISTRICT.

Structurally the Little Popo Agie district is an asymmetrical anticline which is believed to extend southeastward beyond the limit of this field, though the beds forming it are concealed at the end of the field beneath a cover of more recently deposited material which forms a terrace that slopes northeast from the base of the Wind River Mountains. Over the crest of the anticline the beds are vaulted into a flat arch that is sharply flexed on its southwest side. The unsymmetrical character of the fold is best shown in the central part of the district, where the beds on the southwest side are vertical in sec. 11 and dip 82° in sec. 24, T. 32 N., R. 99 W., where Little Popo Agie River enters the anticline. At both ends of the district the beds on this side of the anticline are less steeply upturned than in the central part. On the northeast side of the field the angle of dip ranges from 16° to 46°, and is most commonly between 20° and 30°. Along Twin Creek, in sec. 30, T. 32 N., R. 98 W., the beds on the southwest limb are deflected sharply to the east and form a reentrant angle, a condition which is probably brought about in part by the strike fault in secs. 19, 20, 29, and 32, T. 32 N., R. 98 W. This fault is of the thrust type, with the fault plane nearly vertical. It extends 2½ miles along the strike of the beds and has a maximum throw of 1,180 feet. It decreases in throw abruptly at the southeast end but more gradually to the northwest. The complex areal distribution of the formations affected by this fault is shown on the map (Pl. I). No springs occur along the line of fault and neither oil seeps nor asphalt beds were noted near it. The fault is believed to extend downward to the oil-bearing strata, but the abundant shale in the Chugwater formation has probably sealed the break effectually and prevented the escape of gas or oil.

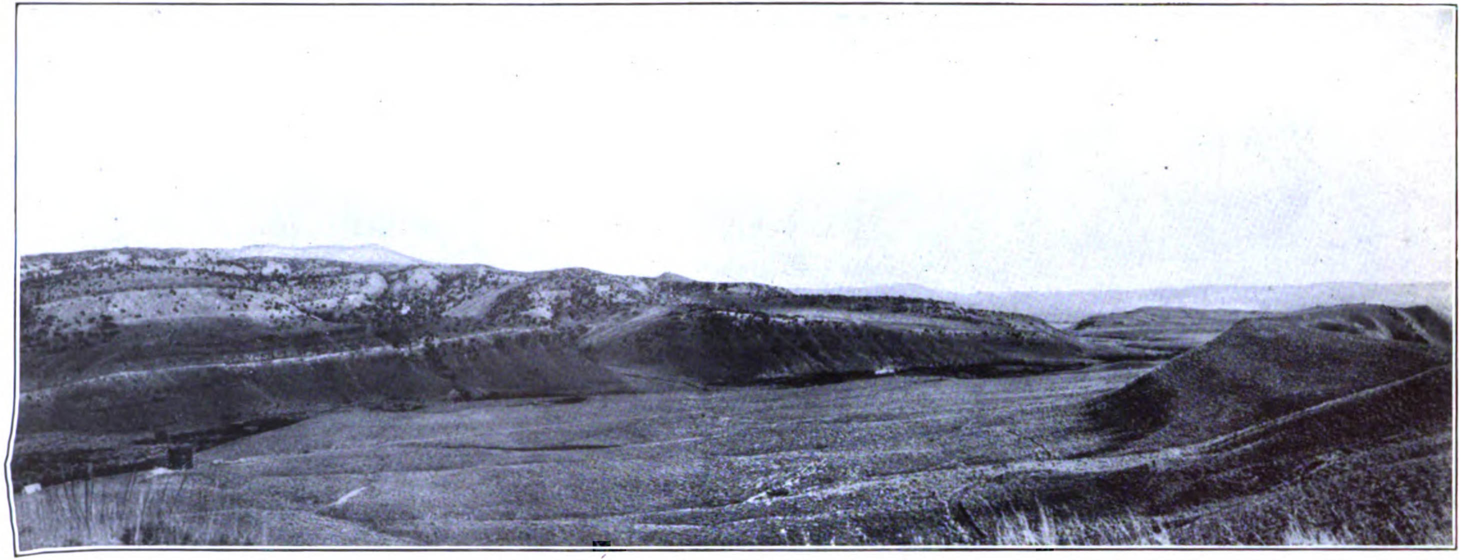
There is another thrust fault, much smaller and transverse to the strike of the strata, in the southwestern part of the district in sec. 9, T. 31 N., R. 98 W. The trend of the fault is N. 64° E., and the maximum displacement of 650 feet brings the Morrison formation against the Chugwater. The fault seems to be a clean break; certainly the zone of disturbance is not more than 25 feet wide. One end is lost in the shale of the Chugwater and the other in the Mancos. A third fault occurs in the Chugwater east of the oil wells, in sec. 13, and extends across the southeast corner of the adjacent section to the east. The maximum displacement along this fault is about 100 feet. Along these faults there are no springs of water, oil seeps, or asphalt beds. Sections A and B, Plate I, show the structure along the lines A–B and C–D. The structure is also shown on Plates III and IV.

BIG POPO AGIE DISTRICT.

The Big Popo Agie district comprises another rise of the crest of the anticline which has been eroded until the red beds of the Chugwater formation are exposed in the center. The structure of the fold is slightly asymmetrical. On the western limb of the anticline the beds are upraised locally as much as 68°, but on the opposite side the dip of the beds is much less except in a narrow zone extending from the river for about 2 miles to the northwest. In that area the dip is as much as 54°. The beds are folded sharply over the crest of the anticline and are less broadly arched than in the southeastern district. An excellent conception of the structure is presented to the observer in the field along the walls of the canyon where Big Popo Agie River cuts the anticline. No faults were observed in the district. A cross section of the structure along the lines E–F is shown by C, Plate I.

LITTLE WIND RIVER DISTRICT.

In Little Wind River district the fold is asymmetrically anticlinal and embraces a local rise along the summit of the uplift. The northwest limit of the fold is concealed beneath one of the large terraces which spread from the Wind River Mountains into the basin, but since the anticline decreases in elevation to the northwest, and is not represented in the escarpment at the opposite edge of the terrace along Big Wind River, it is concluded that the beds gradually flatten and the fold disappears under the terrace cover. The structure is complicated in the northwestern part of the district by a small structural spur which leaves the main fold in sec. 28, T. 1 N., R. 1 W., and after continuing slightly north of west for about a mile it curves to the north and follows the general trend of the main anticlinal axis until it disappears beneath a terrace on the western edge of the field. The beds dip steeply on the southwest side of the fold, being vertical at the point where the Little Wind River crosses the formations between the Chugwater and the Mancos shale, but on the opposite side the beds lie at more moderate angles. The strata are rather broadly arched along Little Wind River, but are lifted into two sharp folds, including a syncline between them, in the northwestern part of the district. Cross section D on Plate I represents this structure along the line G–H, and views *A* and *B*, Plate II, further illustrate the same subject. It should be noted that though no break in the beds was observed in the district an oil spring occurs in the valley on the northwest side of Little Wind River near the crest of the anticline and a hot spring discharging sulphur-bearing water occurs on the southeast side of the stream a short distance southwest of the axis of the uplift. These may result from breaks that are concealed beneath the alluvium of the valley.



VIEW ALONG LITTLE POPO AGIE RIVER NEAR THE MOUTH OF TWIN CREEK, SHOWING OIL WELLS AND STORAGE TANK.

THE OIL.

OCCURRENCE.

Oil was first observed in three springs, one in the valley of Little Popo Agie River, where No. 1 well is situated, another in the northwestern part of the central district, and a third in the valley of Little Wind River, near the axis of the anticline, and 1 mile northwest of the hot-water spring. These oil springs are seeps, from which only a small quantity of oil flowed. In two of the springs the oil is a heavy asphaltic variety, and when it comes to the surface the lighter portions evaporate and leave the asphalt to impregnate the soil, and produce a condition which readily attracts attention. In fact, the asphalt bed is so large that it readily deceives the casual observer into believing that the discharge from the spring has been very large in rather recent time, but the total quantity of asphalt results not so much from the amount of discharge from the spring as from the high percentage of that substance in the oil. The oil from the third spring contains much less asphalt, and therefore leaves less residue.

These springs, together with the favorable anticlinal structure, lead to prospecting for oil. The wells put down in the Little Popo Agie district found oil at the following depths, as shown on Plate V: No. 1, at 300 feet; No. 2, at 400 feet; No. 3, at 750 feet; No. 4, at 697 feet; No. 6, at 1,025 feet; No. 8, at 918 feet; No. 9, at 848 feet; No. 10, at 825 feet, and No. 13, at 697 feet. No considerable quantity of oil was found in wells Nos. 5, 7, 11, and 12, which are reported, respectively, as 1,120, 1,520, 955, and 914 feet deep. The oil is here generally found in the top of the Embar formation, immediately below the base of the Chugwater, the horizon which forms the initial point in the structure contour map, Plate I. Good wells have been developed in local accumulations of oil in the Chugwater, as wells Nos. 1 and 2, whose oil has probably escaped from the Embar.

Oil is reported in a well near the Washakie spring at a depth of 250 feet, in an entirely different formation, the Mowry shale member of the Mancos, which is stratigraphically about 3,700 feet above the horizon of the oil pool at the top of the Embar in the Little Popo Agie region, and about 3,300 feet above the pool in the Chugwater developed by wells Nos. 1 and 2. It is this Mowry formation which yields the oil in the Spring Valley field, in southwestern Wyoming, where it is a paraffin base oil similar to that encountered here and different from that found in the Embar and the Chugwater formations.

SOURCE OF THE OIL.

Investigators who have worked during recent years in surrounding regions assign the source of the oil to various formations. In the Bighorn Basin in northwestern Wyoming C. W. Washburne[a] states that the source of the oil and gas is the black shale at the base of the Colorado. He further remarks, concerning a report of a bed of asphalt, "Apparently the asphalt has exuded from the Pennsylvanian rocks at this place." Wegemann[b] states that in the Salt Creek field, Wyoming, oil is found in the Colorado and in the Montana, and adds further that oil occurs in the Dakota in an adjacent field.

Though oil has been found in several different formations, its occurrence is believed to be controlled strictly by the structure, because as far as known it occurs only near the crest of an anticline.

CHARACTER OF THE OIL.

The oil is dark brown and flows readily as it comes from the wells and becomes slightly thicker on exposure to the air for several weeks. Some of the samples contain a large percentage of water as the oil flows from the wells, but most of this separates from the oil on standing, though in some cases an emulsion seems to have been formed. Samples of oil from six of the wells were analyzed under the direction of David T. Day, expert in charge of petroleum for the United States Geological Survey, with the following results:

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[a] Washburne, C. W., Gas fields of the Bighorn Basin, Wyoming: Bull. U. S. Geol. Survey No. 340, 1908, pp. 351–361.

[b] Wegemann, C. H., accompanying report in this bulletin.

Analyses of oils from Lander field, Fremont County, Wyo.

Serial No.	Well No.	Depth of well.	Physical properties.			Distillation by Engler's method.								Paraffin.	Asphalt.	Unsaturated hydrocarbons.	
			Gravity at 60° F.		Color.	Begins to boil.	By volume.									Crude.	150-300° C.
							To 150° C.		150-300° C.		Residuum.		Total cubic centimeters.				
			Specific.	Baumé.			Cubic centimeters.	Specific gravity.	Cubic centimeters.	Specific gravity.	Cubic centimeters.	Specific gravity.					
		Feet.		°		° *C.*								*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Wyo. 3..	3	750	0.9198	22.2	Dark brown...	93	2.5	....	22.0	(a)	(a)	(a)	(a)	(a)	(a)	50.4	(a)
Wyo. 4..	2	400	.9126	23.4	.....do.........	120	2.0	....	23.5	0.8041	69.9	0.9543	95.4	0.91	4.02	46.4	4
Wyo. 5..	10	825	.9121	23.5	.....do.........	93	2.0	....	21.0	.8067	75.2	.9589	98.2	1.27	5.69	50.8	4
Wyo. 6..	[b] 11	965	.9126	23.4	.....do.........	105	1.5	....	24.0	.8018	73.9	.9605	99.4	.90	11.04	58.0	4
Wyo. 7..	13	697	.9091	24.0	.....do.........	108	2.5	....	23.0	.8047	73.1	.0589	98.6	.62	15.26	50.8	9
Wyo. 8..	Plunkett.	300	.8121	42.4	Green.........	77	14.0	0.7244	41.0	.7994	41.1	.8755	96.1	5.85	.0	10.4	5

[a] Flask broke during distillation. Water in the oil.

[b] No. 11 here is No. 9 on the map.

Dr. Day remarks as follows concerning these oils:

> With one exception these oils are heavy asphaltic oils, differing from one another only in minor details. As might be expected, they are very deficient in gasoline, but yield as much kerosene as can be expected from oils of a specific gravity of 0.9 or more.
>
> The oil from the Plunkett well, near Oil Spring, is significantly different from the others, as shown by the analysis. It is not only free from asphalt, but contains the proportion of paraffin wax characteristic of paraffin hydrocarbons, and is as free from unsaturated hydrocarbons as is usual even with Appalachian oils. That this oil really belongs to the paraffin series is further shown by the low specific gravity of the gasoline portion, 0.7183. Oils of the naphthene or benzol series usually show 0.75 or higher for the gasoline fraction. Although no exact calculation has been made, it is evident that if by diffusion the heavy asphaltic oils found in this region had been deprived of their unsaturated hydrocarbons from, say, 58 per cent down to 8 per cent, these heavy oils would show about 40 per cent of kerosene distillate, instead of 23, and about the proportion of gasoline distillate found in the light oil, and, although this analysis can not be set forward as a proof of this relationship between the heavy and light oils, it makes that relationship somewhat probable.

USES OF THE OIL.

The oil is adapted to several uses. In its native state, when taken from the wells, it can be used for almost any purpose to which crude oil is generally applied. It forms an excellent fuel, comparing favorably with the Texas or California oils, and is now employed for that purpose in practically all the development work in the Little Popo Agie district. It can be used to a limited extent in its raw state as a lubricant, though in general it is not suitable for that purpose. Since oil from the Little Popo Agie district contains a heavy asphalt base, it is a good variety for oiling roads. Fractional distillation gives a small amount of gasoline, a fair amount of illuminating oil, and a considerable residue which can be further separated by distillation into lubricating oil and a tar suitable for use as a fuel or asphalt. The oil shown by analysis No. 8 in the above table is entirely different. It contains a fair per cent of gasoline, a large per cent of illuminating oil, and a residue containing a paraffin base. It is suitable for lubricating purposes. Asphalt is not present in this oil.

MARKET.

The field is located in a sparsely settled country, where the demand for fuel can be supplied from forest and country coal banks and where very little machinery is employed, and consequently only a small quantity of lubricating oil is demanded and, where, also, there is only a small total consumption of illuminants. With these conditions there was practically no demand for the oil previous to the building of the railroad into the region, in 1907. The completion of that work created two markets for the oil. The first was for fuel on the locomotives of the railroad, the second was for various purposes in the towns and cities to which oil can be shipped. As yet the first-named market is practically the only one which has been entered. Oil is reported to have been used on a locomotive running between Casper and Lander for one month during the winter of 1907–8. The use was discontinued, probably because a sufficient quantity of oil was not assured. The local market continues to demand about 50 barrels a day, which is supplied at 75 cents a barrel. All the oil now marketed is produced from the Little Popo Agie district.

PRODUCTION.

The quantity of oil placed on the market has never been large; in fact, the field has not entered the market as an active producer. Mr. Carlisle, who is now in charge of the wells near Dallas, states that their capacity has never been tested, and since they were completed most of them have remained capped. There has been considerable leakage, however, and several years ago there was sufficient waste of oil into Little Popo Agie River to pollute the water. This led to objection by the irrigators using water from the stream, and is reported to have resulted in lawsuits for damages. At present the escaping oil is confined to pools, which are set on fire periodically to prevent an overflow into the river. Very little gas accompanies the oil, and most of it is allowed to escape. A small amount, however, is used about the plant at Dallas, but even in that district the total quantity of gas is insufficient to furnish fuel for pumping and development work. A conservative estimate of the annual production of 1909 for the field is less than 50 barrels a day.

DEVELOPMENT.

HISTORY.

Practically all the development in the field has been confined to the southeastern district, along Little Popo Agie River, in the vicinity of Dallas post office. Previous to 1907 test wells were sunk in other parts of the area, but with little success. The history of operations previous to 1897 is presented by W. C. Knight[a] in his report on this region. Mr. Knight writes:

> The history of this field is far more interesting than that of any other oil field in Wyoming, since it was in this field that Bonneville discovered oil in 1833,

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[a] Knight, W. C., The geology of the Popo Agie, Lander, and Shoshone fields: Bull. Univ. Wyoming School of Mines, Petroleum series, No. 2, Laramie, Wyo., January, 1897, p. 8.

and is the place where the first producing oil well was drilled. From the date of Bonneville's visit up to 1867 the oil spring was unknown except to the hunter and trapper, who frequented the locality to secure the oil for medicinal purposes. Upon the completion of the Union Pacific Railroad people became interested in the natural resources of economic importance, and located, among other things, the Popo Agie oil spring and the surrounding country. This property changed hands several times prior to 1889, but there was no development, except pits sunk as assessment holes. In 1881 Dr. Graff, of Omaha, and associates purchased the oil claims and did considerable surface work. In 1883 and 1884 they drilled three oil wells, all of which were producers. The company then purchased a large number of iron barrels and commenced to market the oil at the Union Pacific Railroad. On account of keen competition from the eastern oil producers the first Wyoming oil company had to abandon their enterprise. Since that time the wells have remained packed. The oil that has flown from the wells through leaks has been utilized by the ranchers for miles about for lubricating purposes, and, to some extent, by the gold mines and the flour mills for steam making.

Since the above sketch was written wells Nos. 4 and 5 (see Pl. V) were drilled in 1901, Nos. 6, 7, 8, and 9 in 1902, and Nos. 10, 11, and 12 in 1903. Very little development work was done during the five years following this period of activity. Recently operations have begun on a more extensive scale than at any preceding time. The present conditions are set forth by districts as follows:

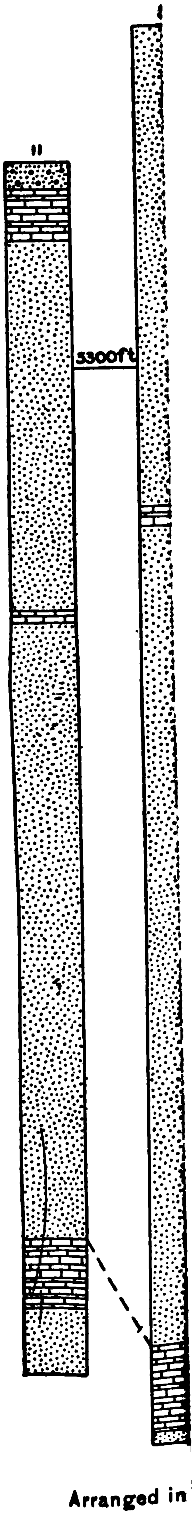
LITTLE POPO AGIE DISTRICT.

Practically all the development work now in progress is confined to the Little Popo Agie district. A 6-inch pipe line has been laid from the group of wells near Dallas post office to a point on the railroad at Wyopa, near Big Popo Agie River. In August, 1909, when the field was visited last, steel storage tanks and pumping machinery were being installed. It is planned to erect receiving tanks at the intake end of the line and storage tanks where the oil is to be discharged. At present oil is hauled from the wells in tanks on wagons to Lander to supply a local market. Three drill rigs were in operation in the district at points marked ○ on Plate I. The Pennsylvania derrick type of standard rig is most commonly used in the district, but some wells are drilled with the common deep-well type. These types are shown on Plate VI, *A* and *B*.

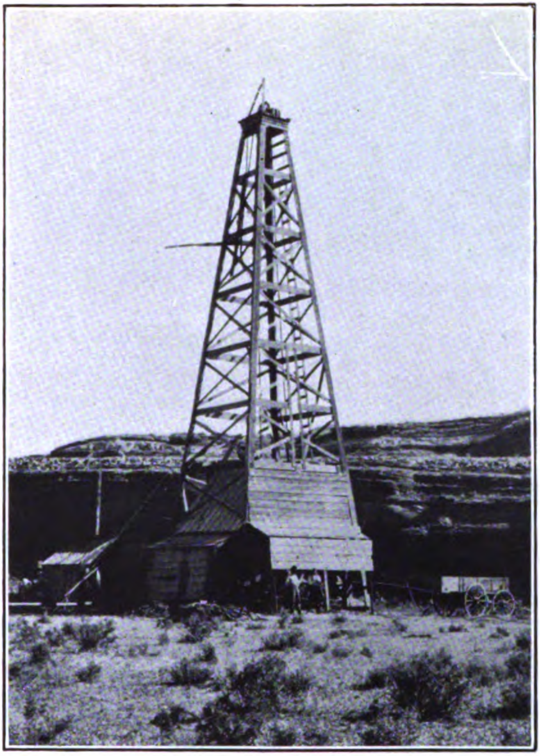
The following detailed information relating to wells in this district was furnished by E. W. Hainsworth, of Lander:

Well No. 1 (Murphy's No. 1); drilled in 1884: A crevice well drilled alongside natural oil spring. Depth said to be 300 feet. Shows considerable gas pressure and flows spasmodically. Tubing is chained to "dead men."

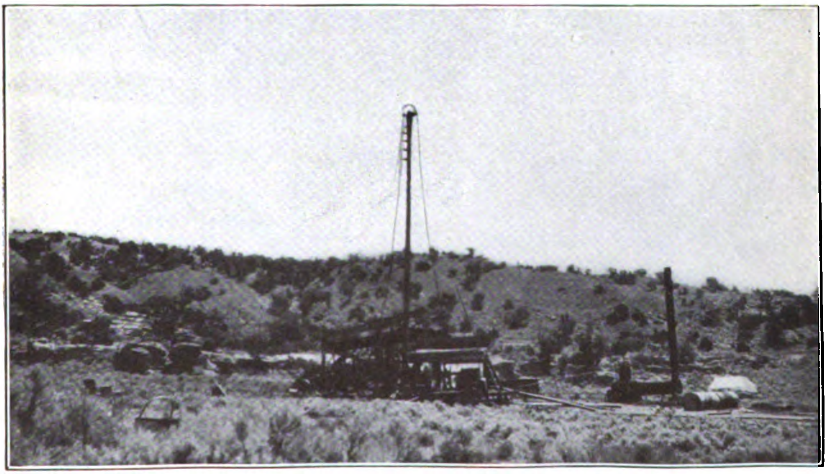
Well No. 2 (Murphy's No. 2); drilled in 1884–1886: A crevice well. Depth said to be 400 feet. Shows considerable gas pressure and flows spasmodically. Tubing is chained to "dead men."



Arranged in



A. HANNON OIL WELL, IN LITTLE WIND RIVER DISTRICT.



B. DRILL RIG AT SMITH AND POTTERS WELL, IN SEC. 25, T. 32 N., R. 99 W.

U of M

Well No. 3 (Murphy's No. 3); drilled in 1884–1886: Well drilled just into the oil sand. Depth said to be 750 feet. Shows considerable gas pressure and flows spasmodically. Tubing is chained to "dead men."

Well No. 4; drilled in 1901: Spudding commenced June 20, 1901; drilling ceased August 21, 1901. Depth of well, 697 feet. Good crevice well; flows spasmodically. Well stopped in limestone capping.

Well No. 5 (Sulphur well); drilled in 1901: Spudding commenced September 4, 1901; work stopped October 8, 1901; drilling recommenced November 7, 1901; finished November 17, 1902. Depth of well, 1,120 feet. A nonproducer; oil sand strong with sulphur water, of which there is a copious flow.

Well No. 6 (Werlen well); drilled in 1902: Spudding commenced July 2, 1902; drilling finished September 5, 1902. Depth of well, 1,025 feet. A good pumping well.

Well No. 7 (Anchor well); drilled in 1901–2: Spudding commenced November 6, 1901; stopped November 26, 1901; recommenced February 19, 1902; stopped again May 14, 1902; recommenced again June 23, 1902, and stopped June 27, 1902. Depth of well, 1,520 feet. Sulphur water and very little oil in hole.

Well No. 8 (Litchfield well); drilled in 1902: Spudding commenced October 13, 1902; drilling finished October 28, 1902. Depth of well, 918 feet. Well just in sand and flows oil spasmodically.

Well No. 9 (Skallawag well); drilled in 1902–3: Spudding commenced December 17, 1902; drilling stopped January 7, 1903. Depth of well, 848 feet. Well produces oil and sulphur water and is a good pumper.

Well No. 10 (Marguerite well); drilled in 1902–3: Spudding commenced November 11, 1902; tools lost November 25, 1902; casing drawn and hole reamed December 28, 1902; tools recovered and well finished March 31, 1903. Well is just through capping and yields considerable oil and gas. Depth of well, 825 feet.

Well No. 11 (Neptune well); drilled in 1903: Spudding commenced January 21, 1903; well finished February 26, 1903. Depth of well, 955 feet. A nonproducer, yielding only sulphur water with little oil.

Well No. 12 (Jupiter well); drilled in 1903: Spudding commenced March 16, 1903; well finished April 10, 1903. Depth of well, 914 feet. A nonproducer, yielding much sulphur water and little oil.

Well No. 13 (Titania well); drilled in 1903: Spudding commenced April 20, 1903; well finished May 19, 1903. Depth of well, 697 feet. Good well; flows spasmodically.

BIG POPO AGIE DISTRICT.

The most active development in the Big Popo Agie district was undertaken in connection with the pipe line that begins in the southeastern district and terminates at the railroad in the valley of Big Popo Agie River. The Plunkett well, in sec. 25, T. 1 S., R. 1 E., Wind River meridian, near the Washakie oil spring, was being drilled at the time that portion of the field was surveyed and, according to later reports, struck a high grade of oil at a depth of 250 feet. If the statement is true this oil occurs in Mancos shale at a horizon that is stratigraphically 3,300 feet higher than that of the oil in any well in the Little Popo Agie district.

LITTLE WIND RIVER DISTRICT.

Previous to 1909, according to report, no development was begun in the Little Wind River district. In the spring of 1909 one well, now abandoned, was sunk by the Washakie Hydrocarbon Mining Co. in the valley of Little Wind River, at the point marked Tar Spring on the map (Pl. I). The following information relating to this well was furnished by Russel Thorp, president of the Company:

Log of well No. 1—Washakie Hydrocarbon Mining Co.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, some gravel	25	25
Bed rock	40	65
Clay, blue, very soft	100	165
Limestone, from which cold sulphur water flows	6	171
Shale, blue, very soft, oil present (artesian flow of warm sulphur water)	129	300
Shale, blue	50	350
Limestone (second artesian flow warm sulphur water)	5	355
Shale, blue	50	405
Sandstone, brown	15	420
Quartz and flint	5	425
Shale	75	500
Limestone, slight conglomerate, hard (third flow warm sulphur water)	40	540
Clay, soft blue; oil present	15	555
Limestone	15	570
Flint	5	575
Sand carrying oil	25	600
Limestone	25	625
Sandstone; some crystalline formation	25	650
Sand; additional and stronger flow of oil	25	675
Very hard, white, gritty formation	125	800

Water: At 165 feet, cold sulphur water; at 300 feet, artesian flow warm sulphur water at rate of 1,450 barrels a day (24 hours); at 350 feet, additional artesian flow warm sulphur water (flow of water from tar springs decreasing); at 500 feet, third artesian flow of warm sulphur water up to 3,000 barrels a day; at 540 feet, February 23 flow from tar springs stopped entirely. The continuous flow since March 16, 1909, has settled down to a steady flow of 20 barrels a day. The different flows of water could be plainly noted, both by the increase in flow and by the added fumes and gases, which affected the men's eyes to such an extent that work had to be shut down from one to three days until the gases subsided, although a decided odor of sulphur may be noted up to the present time.

Drilling: Spudded January 30, 1909, with 39 feet of 10-inch conductor; 10-inch bit used to 405 feet, when attempt was made to shut off water in the brown sand, without success. The diameter of the hole was reduced at this point to 8 inches and 8-inch hole was carried to depth of 555 feet. At 500 feet bits wore down rapidly; at 540 feet tools stuck in blue clay; at 555 feet to bottom of rimming casing was set in without successful shut-off or reduction of water bailing. Casing settled 4 feet in three days. Set 672 feet of 6¼-inch casing. Eighty pounds of wheat used to swell bottom, apparently without success. From 675 feet to bottom of hole, 800 feet, very hard rock that wore the bits rapidly.

The entire drilling was conducted in water continuously, from 165 feet down, and the hole stood up with practically no casing.

Oil was present in the formation at 171 feet. At 650 feet there was a perceptible flow of oil, which increased. At 670 feet a second oil stratum was encountered, which shot oil all over the place and afforded a continuous flow of oil as long as the tools were in motion; when the tools were removed the flow subsided. The fine white sand to the bottom carries oil.

The second well in the district is located in the valley of Sage Creek, in sec. 22, T. 1 N., R. 1 W. The following log was reported July 8 by the driller, who was still engaged in sinking the well.

Log of well in sec. 22, T. 1 N., R. 1 W.

	Thickness.	Depth.
	Feet.	*Feet.*
Gravel	58	58
Not reported	7	65
Sand rock, red	385	450
Shale, gray	5	455
Sandstone, red	675	1,130
Limestone with a flow of sulphur water at the base	70	1,200
Sandstone, gray	197	1,397
Shale, blue	12	1,409
Sandstone, gray	14	1,423
Limestone to bottom	27	1,450

Subsequent to the examination of the field it was reported that a bed of asphalt was encountered in this well only a short distance below the maximum depth shown by the above record. The writer has been unable to verify the statement or to examine a sample of the product.

In June, 1910, Mr. Winchester revisited the region to procure any additional data which might be obtainable as a result of operations in the field since the survey of the previous year. He found that although there had been considerable development, nothing had been discovered by the operations to alter the conclusions here stated concerning the geology and the oil.

On July 1, 1909, only 13 wells had been completed; on July 1, 1910, 27 had been completed and five were being drilled. The pipe line from Dallas to Wyopa was finished, and was carrying oil from the wells to two storage tanks having a capacity of 37,500 barrels each. Oil is supplied to three oil-burning passenger engines which operate between Lander and Chadron, Nebr. The price paid by the railroad is reported to be 2 cents a gallon. As had been expected, practical tests have proved that this oil is an excellent fuel.

The Plunkett well, already referred to, is reported by the operators to be producing 60 barrels of high-grade oil a day, part of which is sold locally at $1 a barrel and the rest is hauled to Lander, where it is converted into gasoline and a residue in a small refinery. One of the wells is reported to have reached a depth of 2,000 feet. It discharges daily about 2,000 barrels of water containing carbon dioxide and sulphur, with only a trace of oil. Thirteen wells, producing about 330 barrels of oil a day, are now supplying oil to the pipe line, and other wells will be connected with the line as soon as possible. Several wells are being drilled, and prospecting has been undertaken in earnest.

THE SALT CREEK OIL FIELD, WYOMING.

By Carroll H. Wegemann.

INTRODUCTION.

ACKNOWLEDGMENTS.

In presenting the following report on the Salt Creek oil field of Wyoming the writer desires to express his thanks for valuable suggestions and criticism to M. R. Campbell, who had general supervision of the work, and to R. W. Stone, both of whom were in the field during the beginning of the investigation. The author is also much indebted to Dr. T. W. Stanton, who visited the field in 1910, and who made the fossil determinations. The major part of the field work was done in the fall of 1909, the writer being assisted by Ralph W. Howell and William Mulholland. The work was completed in 1910 by the author, assisted by C. J. Hares.

LOCATION OF THE FIELD.

The Salt Creek oil field is located in Tps. 38 to 41 N., Rs. 78 and 79 W. of the sixth principal meridian, in the northeast corner of Natrona County, Wyo. It lies in the drainage basin of Powder River, about 50 miles due north of Casper and 80 miles southeast of Buffalo. The country is open and easily accessible, but there has been little travel in the region and consequently roads are few. The field may be reached by three roads. The easiest line of approach is from Casper, on the Chicago & Northwestern Railway, by private conveyance over a wagon road that runs directly northward to the field. The next easiest line of approach is from Sheridan or Clearmont, on the Chicago, Burlington & Quincy Railroad, by stage to Buffalo, thence by stage to Kaycee, and thence by private conveyance southeastward over a wagon road directly to Shannon, in the north end of the field, a total distance of about 130 miles. The third road, least traveled, runs from Buffalo to Sussex, in the valley of Powder River, and from that place to Shannon. In traveling from Shannon to Casper the first permanent ranch is south of the divide, about 30 miles from the oil field. Between Shannon and Kaycee there are a few ranches, the nearest being 12 or 15 miles from Shannon. North of Shannon the nearest ranches are in the valley of Powder River, 20 miles distant. In the oil field a road house at Shannon is maintained for the accommodation of travelers, and several drilling camps have been established. There is at present no post office at Shannon. Mail for the field is usually addressed to Casper.

HISTORY OF DEVELOPMENT.

It is difficult to obtain trustworthy information concerning the early history of the Salt Creek field, for the numerous accounts presented do not entirely agree. Knight states that oil was reported from this area prior to 1880.[a] The occurrence of oil was well known a few years later. It is said that A. T. Seymore took up the first oil claims in the field in 1885 or 1886. Seymore was a civil and mining engineer and compiled a map of the oil fields of central Wyoming. C. Y. Iba was also interested in the development of the field. An "oil spring" which bears his name is situated in the bed of Salt Creek, in the SE. ¼ SW. ¼ sec. 13, T. 40 N., R. 79 W. Samuel Aughey,[b] territorial geologist for Wyoming, describes it as follows:

> When I last visited this spring, in May, 1884, not less than 20 barrels of oil had accumulated in the creek bed. The rise of the creek from a rainfall one night washed it away, but it immediately commenced again to accumulate, and in less than a week the original quantity was stored.

At the present time oil does not collect in noticeable quantity in the creek bed. A small sand bar in the middle of the creek marks the site of the spring at a point where the creek bends to the north with a cut bank on the east side, along the crest of which the Casper road runs. The surface of the sand is black and greasy, and on digging into it the smell of petroleum becomes very marked.

P. M. Shannon, of the Pennsylvania Oil & Gas Co., was the first to begin actual development in the field. The first well, Shannon No. 1, was located in the SE. ¼ SE. ¼ sec. 36, T. 41 N., R. 79 W. This well was drilled in 1889, and three more wells were drilled in the next two years. By 1893 rates had been obtained from the railroad and the shipment of oil was begun. The oil was hauled to Casper by wagon, a distance of 50 miles, 12 to 16 horse teams being employed. In 1895 the Pennsylvania Oil & Gas Co. erected a refinery at Casper and put down wells 5, 6, 7, and 8, W. H. Smith being the driller. In 1901 well No. 9 was completed, and in 1902 Nos. 10, 11, 12, and 13.

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[a] Knight, W. C., Geology and technology of the Salt Creek oil field: Bull. Univ. Wyoming School of Mines, Petroleum series No. 1.

[b] Ann. Rept. Territorial Geologist of Wyoming, 1886.

These wells yield a heavy lubricating oil of rather high viscosity, containing little or no naphtha, asphalt, or sulphur, but more than 1 per cent of paraffin. By reflected light its color is olive green; by transmitted light it is red. Its gravity is 0.9097 (23.9 Baumé). It is chiefly valuable for lubricating.

In 1905 (?) the Pennsylvania Oil & Gas Co. sold its entire property to Mr. Lobell. He in turn sold a few acres in the NE. ¼ sec. 2, T. 40 N., R. 79 W. to a French company called the Ascos, under the management of Mr. Delvaux, who drilled four wells in 1906. In 1906, also, Dr. Porro, an Italian geologist, examined the field and made a private report. It is said that he located the well afterward drilled by the Petroleum Maatschappij Salt Creek, a Holland company, in the SE. ¼ sec. 23, T. 40 N., R. 79 W., about 3 miles south of Shannon. The well was not drilled until the fall of 1908. On October 23 of that year oil under great pressure was struck in sandstone about 1,000 feet below the surface. This well was drilled by J. E. Stock and was the first to strike the lower sand, here named Wall Creek sandstone lentil.

This oil, in contrast to that obtained from the Shannon wells, is a light gasoline oil containing 16 per cent of naphtha, 29 per cent of water-white oil, and 6 per cent of paraffin. In color it is a very dark green by reflected light and reddish brown by transmitted light. It is valuable, first, for the illuminating oils and, second, for the lubricating oils which it contains.

Before this "gusher" well was put down, a well known as the "Iba" was drilled by J. E. Stock in the NE. ¼ SE. ¼ sec. 22, on Bothwell Draw. Some oil was encountered in the shale, but scarcely in paying quantities. After the completion of the "gusher" well the Stock Oil Co. was formed and a well was drilled in the SW. ¼ NE. ¼ sec. 25, T. 40 N., R. 79 W. Some oil was encountered in shale, but the sand was not reached. During the year 1910 several new companies have entered the field and development has progressed rapidly. The Lobell interests have been bought out by the Franco-American Oil Co., which has drilled four new wells at the northern end of the dome near Shannon.

The California Oil Company completed the old Stock well and drilled several new wells in the south half of the dome, which have added materially to our knowledge of the extent of the oil pool. The Maatschappij Company drilled three wells in 1910, all of which reached the sand.

Several wells that have been drilled outside of the producing area deserve mention. The first of these was put down by the Pennsylvania Oil and Gas Company when it first entered the field, at the junction of Teapot Creek and Salt Creek, in the SE. ¼ sec. 16, T. 39 N., R. 78 W. The site is marked by a pool of alkaline water close to the bank of the creek. The record of the well was not preserved. In 1895 the Wyoming Lubricating Company drilled to the depth of more than 1,200 feet near the center of sec. 31, T. 41 N., R. 78 W., without encountering oil, and abandoned the well. Mr. H. W. Davis, of Sussex, drilled a well near the east line of sec 12, T. 41 N., R. 80 W., which passed through the Shannon sandstone lentil, and obtained a slight showing of oil. The well was continued to a depth of 1,200 or 1,300 feet and was abandoned. In the SW. ¼ sec. 16, T. 40 N., R. 80 W., a little east of the outcrop of the Wall Creek sandstone lentil, a well was drilled to a depth of 1,200 feet by the French Oil Company. The well must have passed through the Wall Creek sandstone lentil, but did not encounter oil. A small amount of gas was obtained, however. At the present time the well flows a 1-inch stream of lukewarm sulphur water, and from a hole in the top of the plug gas rises which, when ignited, burns with a flame about 6 or 8 inches high. It is probable that the gas comes from the Wall Creek sandstone.

TOPOGRAPHY.

RELIEF.

The country in general aspect is barren and desolate. Though it is traversed by numerous deep valleys the effect of relief is lost in the distance, the somber colors of the treeless hills causing one to fade into the next, forming a vast, rolling expanse, whose prevailing tones are brown and gray. Above this expanse rise bold escarpments, formed by the tilted edges of sandstone strata. Some of these escarpments can be seen for many miles and form conspicuous landmarks. These escarpments are important in this discussion, since some of them bear oil, and all of them, being easily recognized, form convenient key rocks by which the geologist can determine relative position in the stratigraphic section. These will be described in more detail in the following pages.

The rocks over the central portion of the Salt Creek dome have been removed by erosion, which has here formed an anticlinal valley. Around this valley runs an escarpment formed by the cut edge of the Shannon sandstone lentil. Outside of this, but not completely encircling the dome, are escarpments formed by higher beds of sandstone, and between them are valleys which are developed on the intervening shale.

Within the Salt Creek dome and east of the creek broad flats have been formed by the stream. The greater part of the area, however, within the escarpment of the Shannon sandstone lentil is occupied by bad lands developed on the shale. These represent the mature type of topography—the stage when relief is greatest. The streams have cut deep, narrow valleys in the shale, but have not had time to lower the hill crests between or to make the slopes gradual. As these changes take place—as the hills are reduced in height and the valleys are widened—a type of topography is produced which in this area is exemplified by the broad flats above mentioned.

In this area several of the streams are located on anticlines, forming what are known as anticlinal valleys. The present relief is thus the reverse of that produced by the folding of the rocks, the surface on several of the anticlines being lower than that in the adjoining synclines. On the flanks of the rock folds, where the dip of the strata brings alternating soft shale and hard sandstone to the surface, the shale is eroded rapidly, forming valleys, and the sandstone is left in escarpments.

Three prominent beds of sandstone produce the escarpments—the Shannon sandstone lentil, the lower part of the Parkman sandstone member, and the stratigraphically higher sandstone which forms Little Pine Ridge. The first of these completely encircles the Salt Creek dome and forms the ridge trending north and south about 3 miles west of the dome. In the northern part of the area this sandstone is less conspicuous as a cliff maker, but toward the south it rises in sheer cliffs, some of them 100 feet or more in height. So far as observed the ridge formed by this sandstone does not bear pine trees, as does Little Pine Ridge and the ridge formed by the Parkman sandstone member.

The lower part of the Parkman sandstone member, about 1,300 feet above the Shannon sandstone lentil, forms the most marked escarpment in the field. Erosion has carved this massive sandstone into many strange and picturesque forms. Isolated masses stand here and there like turrets and domes above the rolling, grass-covered surface of the surrounding country; elsewhere the sandstone rises in great cliffs, partly covered by pine trees and forming striking features, which may be seen from a distance of many miles. (See Pl. IX, *A*.)

Little Pine Ridge is a much less prominent escarpment than those just described. The sandstone is bluish, and as it almost invariably bears pine trees it is easily followed throughout the field. (See Pl. IX, *B*.)

Two other sandstones form local ridges. One of these, between the Shannon sandstone lentil and the Parkman sandstone member, forms a ridge about 4 miles long in the NW. ¼ T. 40 N., R. 78 W., and the

NE. ¼ T. 40 N., R. 79 W. This sandstone is not recognizable in other parts of the field. The second sandstone, which lies about 325 feet above the standstone forming Little Pine Ridge, can be traced throughout the field and forms several prominent escarpments.

DRAINAGE.

Salt Creek, the principal stream of the field, rises about 25 miles southeast of Shannon and flows in the general direction N. 30° W., joining Powder River at the Davis ranch, in the SE. ¼ sec. 15, T. 43 N., R. 79 W., its total length being about 50 miles. During the summer the creek flows only in rainy weather, the water ordinarily standing in pools along a dry bed. It is therefore mapped as an intermittent stream, although it is of considerable size. It enters the area at the southeast corner of T. 39 N., R. 78 W., and leaves it near the middle of the north line of T. 41 N., R. 79 W. In the southwest corner of T. 40 N., R. 78 W., it makes a decided bend to the west and, crossing the outcrop of the Shannon sandstone lentil, enters the Salt Creek dome, where it is joined in sec. 25, T. 40 N., R. 79 W., by Castle Creek. It then turns northward and leaves the dome, crossing the Shannon sandstone again in sec. 12, T. 40 N., R. 79 W.

The principal tributaries of Salt Creek in the field are Dugout Creek, Castle Creek, and Teapot Creek with its branch, Little Teapot.

WATER SUPPLY.

Water for drinking and domestic use is somewhat difficult to obtain. The surface water and that reached by drilling are both alkaline. The water in Salt Creek, when that stream is flowing, can be used, but it is not altogether palatable. The water in Castle Creek during dry weather is so bad it is hardly fit for the use of stock. No analysis has been made of the water, but it probably contains sulphates of magnesium and sodium in large amounts. At the oil wells all water for domestic use is distilled in pipes attached to the boilers.

GEOLOGY.

STRATIGRAPHY.

CRETACEOUS SYSTEM.

The rocks to be directly considered in a study of the Salt Creek oil field belong to the upper part of the Cretaceous system of the Mesozoic, which is known as Upper Cretaceous series. (See accompanying table.)

Rock formations in Salt Creek oil field, Wyoming.

System.	Series.	Group.	Formations and number recognized in this field.		Character.	Thickness in feet.
Tertiary.	Eocene.		Fort Union formation.		Fine grained fresh-water sandstone, shale, and coal beds.	Several thousand feet.
Tertiary or Cretaceous.	?		Lance formation.		Concretionary buff sandstone and shale bearing Triceratops remains. Fresh water.	3,200
Cretaceous.	Upper Cretaceous.	Montana.	Fox Hills sandstone.		White sandstone and shale. Marine.	700?
			Pierre formation.		Shale with several sandstone beds, including that which forms Little Pine Ridge. Marine.	1,000
				Parkman sandstone member.	Massive buff sandstone overlain by shale and thin coal beds. Marine and fresh water.	350
					Shale with sandstone stratum 250 feet above its base. Marine.	1,100
				Shannon sandstone lentil.	Oil-bearing horizon near base. Marine.	175
					Gray shale. Marine.	1,025
		Colorado.	Niobrara shale.		Light-colored shale in parts, somewhat arenaceous. Marine.	735
			Benton shale.		Dark shale, several calcareous beds. Marine.	220
				Wall Creek sandstone lentil.	Buff sandstone, ripple marked, and cross bedded. Petrified wood, marine shells and fish teeth. The principal oil sand of Salt Creek.	80
					Dark shale, several sandstone beds. Marine.	800
				Mowry shale member.	Firm slaty shale, usually forming escarpment. Weathers light gray and bears numerous fish scales. Marine.	300
					Dark shale with one thin, persistent, strongly ripple-marked sandstone.	270
			Dakota(?) sandstone.		Conglomeratic sandstone, oil bearing. Fresh water.	56
Jurassic?			Morrison formation.		Variegated shale with several sandstone beds which in certain localities bear oil. Fresh water.	250

DAKOTA (?) SANDSTONE.

The lowest Upper Cretaceous formation in this region, according to the usual classification, is the sandstone called the Dakota, which here rests upon the variegated shale of the Morrison formation. By some authors, however, the Morrison is placed in the Cretaceous system.[a] Its sandstones bear oil, but in doubtful quantity.

The sandstone here called the Dakota may or may not be the Dakota. It occupies the same stratigraphic position as the formation described by Darton[a] as the Cloverly, which is supposed by him to represent the Lakota, Fuson, and Dakota of the Black Hills, or, in other words, to represent the later Lower Cretaceous deposits and the earliest Upper Cretaceous deposits. Fisher[b] correlates the Cloverly formation of the Bighorn of Wyoming with the Kootenai of Montana and believes it to be of Lower Cretaceous age.

The Dakota sandstone does not outcrop in the Salt Creek field, although it doubtless underlies it. Some 20 miles west of the field it is brought to the surface in the Powder River dome, where it is composed of 55 feet of conglomeratic cross-bedded oil-bearing sandstone. (Pl. VIII, *B*.) At its base in many localities there is a thin coal bed and particles of coal occur throughout the conglomerate. The only fossils found in the formation are the impressions of small leaves and these are by no means numerous. In the Powder River field the Dakota is a definite sandstone unit, but in areas farther north it is not so well defined. The sandstone is not conglomeratic and is interbedded with shale. Its exposures in this area have been described by N. H. Darton, under the name of Cloverly.

COLORADO GROUP.

Benton shale.—Upon the Dakota (?) sandstone, in apparent conformity, lies the Benton shale, 1,700 feet thick, containing sandstone beds and, in its lower part, the cliff-forming fish-scale shale known as the Mowry siliceous shale member. The lowest of the sandstone beds occurs 80 feet above the top of the Dakota sandstone. It is 14 feet thick, the lower part consisting of thin-bedded sandstone and shale, the top layers of firm sandstone, strongly ripple marked. This sandstone bed, though comparatively thin, is found throughout a considerable area in this region. It usually forms a marked plateau or terrace.

About 170 feet above the sandstone just described is a thin sandstone bed at the base of the Mowry. In some places this bed forms a

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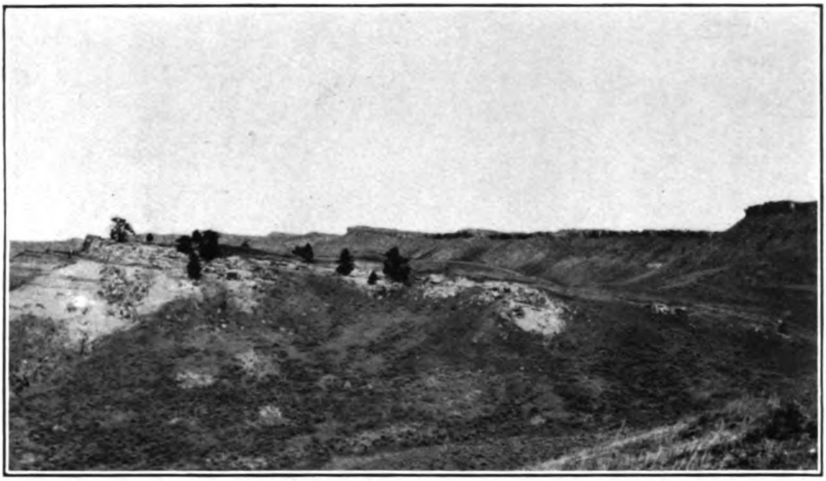
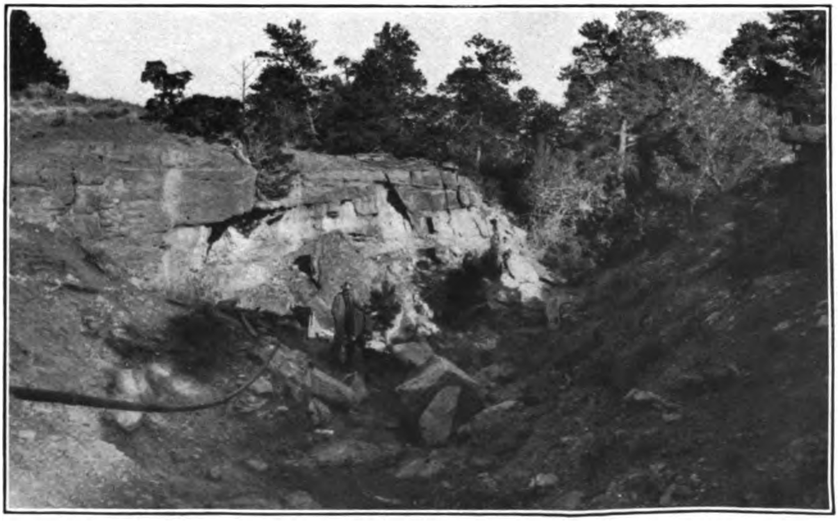
[a] Darton, N. H., Geology of the Bighorn Mountains: Prof. Paper U. S. Geol. Survey No. 51, 1906.

[b] Fisher, C. A., Southern extension of the Kootenai and Montana coal-bearing formations in northern Montana: Econ. Geology, vol. 3, No. 1.



A. ESCARPMENT EAST OF WALL CREEK.

Wall Creek sandstone lentil on right. Sandstone bearing pines is 220 feet below.



B. DAKOTA (?) SANDSTONE AND OPEN OIL WELL IN OIL CAÑON, POWDER RIVER OIL FIELD, 18 MILES WEST OF SALT CREEK.

Iron pipe on left leads from the well.

conspicuous white ledge, in others it dies out almost entirely. At its base is a horizon represented by carbonaceous shale or petrified wood, and at one locality by a thin bed of coal. The Mowry shale member, 300 feet in thickness, is a phase of the Benton which is easily recognized. Its outcrop almost always forms a prominent ridge. The shale weathers white and on examination shows great numbers of fish scales. At its top occurs a 5-foot bed of bentonite (a hydrous silicate of alumina), which forms a conspicuous white band in the slopes and in wet weather becomes so exceedingly slippery that it is dangerous to cross on horseback. Above the Mowry are 800 feet of shale and sandstone. The sandstone occurs in several beds which change considerably in character from place to place. At some places one is conspicuous, at others another. Usually, however, at least one of these beds forms marked cliffs in the interval between the top of the Mowry and the base of the oil-bearing sand of the Benton, to which the name Wall Creek sandstone lentil is here given.

The Wall Creek sandstone lentil, like the other rocks thus far described, is not exposed in the Salt Creek field. It reaches the surface in an escarpment 12 miles west of Salt Creek, which rims the Powder River dome much as the Shannon sandstone lentil rims the Salt Creek dome. It forms the lofty escarpment around the Powder River dome, known locally as "The Wall," and is best exposed above Wall Creek, a little stream named from it. (See Pl. VIII, *A*.)

Along Wall Creek the sandstone is between 80 and 100 feet in thickness, but in the Salt Creek dome thicknesses as great as 150 feet are reported in some of the wells. The sandstone is buff in color, firmly cemented, and of medium grain. Cross-bedding and ripple marks are common. It contains numerous fossils, prominent among which are *Prionocyclus wyomingensis* and species of *Inoceramus*. Fossil wood showing worm borings is present in many places. The Wall Creek sandstone lentil is overlain by shale.

Niobrara shale.—About 220 feet above the top of the Wall Creek sandstone the dark shale of the Benton gives place to sandy shale, buff or bluish gray in color, of Niobrara age. It contains fragments of very thick-shelled *Inoceramus*, to which are attached in clusters numerous shells of *Ostrea congesta*, a small oyster. The association of these two fossils is typical of this formation. Exposures of the Niobrara shale are usually concealed in a broad valley, and the limits of the formation are somewhat difficult to establish and trace. The lower limit, as already mentioned, is placed a little over 200 feet above the top of the Wall Creek sandstone lentil. At this point the shale changes abruptly from dark to light in color and is somewhat more sandy in composition. At this point also *Ostrea congesta* appear in considerable numbers; below it only isolated specimens can be found.

At the top of the formation are two or three thin beds of limestone only a few inches in thickness. *Ostrea congesta* are fairly abundant in the shale below these beds of limestone, but above them none could be found. At several places large *Baculites* distinctive of the Montana group were found a short distance above these limestone beds. At the limestone horizon, also, there is a slight change in lithologic character of the shale. Above the limestones there are numerous very thin beds of reddish calcareous shale, whereas below none is found. The peculiar structure known as "cone in cone" is also common above the limestones, but does not occur in the Niobrara. The amount of alkali in the Montana group is apparently greater than in the Niobrara shale, as indicated by the white alkali deposited on the surface by evaporation. These differences, although perhaps unimportant in themselves, furnish a convenient means of separating the Niobrara from the overlying Montana where fossils can not be found.

Owing to the lack of exposures the thickness of the Niobrara shale is difficult to determine. Three sections made along the outcrop from 1 to 4 miles northwest of Kaycee give an average of 735 feet. Another section at the southeast side of the Powder River dome, about 4 miles southwest of Scott's ranch, gives a thickness of 1,025 feet, which is unusually great. Exposures in this locality are good and there seems to be little chance of error unless concealed faults have duplicated the beds. Even if this section is disregarded, however, it is evident that the Niobrara in this general region is of unusual thickness as compared with other localities, although much less distinct in lithologic character.

MONTANA GROUP.

Pierre formation.—Above the Niobrara shale the gray shale of the Pierre extends uninterruptedly for 1,000 feet. It weathers into "adobe hills" producing a type of topography that is monotonous and uninteresting. As stated above, the shale contains numerous thin beds of firmer calcareous shale stained red by oxide of iron. At a few places also lenses of other material occur. In T. 40 N., R. 79 W., a peculiar conglomerate was observed about 375 feet above the base of the Pierre. It is for the most part brick red in color, but contains a few black, well-rounded pebbles and numerous fish teeth (p. 54, *t*). The bed is not over 2 feet thick and can be traced for only a mile along its outcrop. In sec. 14 of the same township is a thin red sandstone containing dark pebbles. A bone of a swimming saurian was found on its surface. The bed is small in extent and lies about 200 feet stratigraphically above the fish-tooth conglomerate just described. These sandstones are evidently lenses in the shale. The principal fossils in this portion of the Pierre are large *Baculites*, but even these are not numerous.

Upon the shale just described lies a sandstone which forms the rim rock of the Salt Creek dome. South of Shannon this sandstone has a thickness of 170 feet. It is somewhat variable in character, but usually contains two resistant beds, about 100 feet apart, and an intermediate mass of softer sandstone. It is here named the Shannon sandstone lentil. The heavy lubricating oil of the Shannon field occurs near the base of this sandstone, which is further described under the heading "Oil sands" (p. 65).

Above the Shannon sandstone lentil is 1,100 feet of shale, with a 30-foot bed of sandstone, locally occurring 225 feet above its base (p. 53, *q*). About 100 feet below the top of this shale are definite marine Montana fossils. Here also was found a vertebral centrum doubtfully determined as *Mosasaurus*. (See p. 54, *o;* also pp. 50–51, *c*, *d*, *e*, *g*.)

Above the shale just described occurs a series of beds of sandstone, coal, and shale, about 300 feet thick, which bears a fauna similar to that found in the upper Claggett of Montana, the Parkman sandstone of Wyoming, and the Mesaverde formation of Colorado. The name Parkman is adopted in this report, since this name has been used by Darton[a] for the sandstone as it outcrops along the flank of the Bighorn uplift.

At the base of the Parkman sandstone member is about 40 feet of shaly sandstone, and above this a massive white to buff sandstone, 100 feet thick, which shows much cross-bedding. Its outcrop forms a striking escarpment (Pl. IX, *A*). Almost at the base of this massive sandstone near Shannon, R. W. Stone collected fossils which were identified by Dr. Stanton. (See p. 50, *a;* also pp. 51, *h*, 52, *a*, *k*). Large bones have also been found embedded in the sandstone. The writer measured one which was 6 inches in diameter and 2 feet 6 inches long in its exposed portion. The entire bone was considerably longer. It was identified by C. W. Gilmore as the distal half of a femur of an animal belonging to the genus *Trachodon*. Turtle shell was found in association with it.

A group of thin coal beds, dark shale, and white sandstone, the whole 125 feet thick, increases the height of the sandstone escarpment or forms a second escarpment outside it. These beds apparently represent alternating brackish-water and fresh-water conditions. Some of the strata contain considerable iron, which gives them a brownish cast. The contrast in colors—white, black, brown, and gray—between the numerous thin beds of this group is striking. The coal beds are less than 14 inches thick in this field. They occur at the same horizon as those mined 50 miles farther south, near Casper. ("Coal B," Shaw's map.[a])

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[a] Darton, N. H., Geology of the Bighorn Mountains, Prof. Paper U. S. Geol. Survey No. 51, 1906; Bald Mountain-Dayton folio (No. 141), Geol. Atlas U. S., U. S. Geol. Survey, 1906; Cloud Peak-Fort McKinney folio (No. 142), Geol. Atlas U. S., U. S. Geol. Survey, 1906.

Near the top of the fresh-water beds just described is a white sandstone, 10 to 40 feet thick, and above it in certain localities is a thin calcareous layer in which are embedded fragments of dinosaur bones, among which a caudal vertebra of *Trachodon* was identified. At this horizon, in the SW. ¼ SE. ¼ sec. 23, T. 41 N., R. 79 W., a dermal scute of an ancient crocodile was obtained, but no other bones were found in the vicinity (p. 54, *u*). Only one other specimen of this crocodile has been found and that occurred in the Judith River formation of Montana. It was described and named by Dr. W. J. Holland as *Deinosuchus hatcheri*, and is estimated to have been from 35 to 40 feet in length.[b]

About 30 feet above the dinosaur horizon invertebrate fossils were collected (see pp. 51, *f*; 52, *i*, *j*, *k*; 53, *r*), of which Dr. T. W. Stanton says:

> They belong to a phase of the Montana fauna very similar to that which occurs in the upper Claggett. near Billings, Mont., and the Mesaverde of the Laramie plains, near Harper, Wyo.

From these marine forms it is evident that salt-water conditions were soon reestablished after the deposition of the coal beds. Above the stratum in which these fossils occur soft sandstone alternates with shale for an interval of 325 feet. These strata bear occasional Montana fossils. Overlying them is the sandstone forming Little Pine Ridge, a bluish white sandstone, 50 feet thick, containing two thin beds of coal, which, like the other coal of this general region, is subbituminous. The sandstone forms a ridge (Pl. IX, *B*), which, by the color of the rock and the occasional pine trees it bears, is easily traced throughout the field southward to the vicinity of Casper and thence eastward for 30 miles along the base of the Laramie Mountains, where it is reported to form a more prominent ridge than the massive sandstone comprising the base of the Parkman. To the north, however, near Kaycee, Little Pine Ridge can scarcely be recognized, although the escarpment of the Parkman sandstone is prominent in this region. The coal occurring in the sandstone of Little Pine Ridge is occasionally mined for local use in the NW. ¼ NW. ¼ sec. 32, T. 41 N., R. 78 W., where it is 26 inches thick. It is lower in grade than the Fort Union coal, exposed 10 miles to the northeast,

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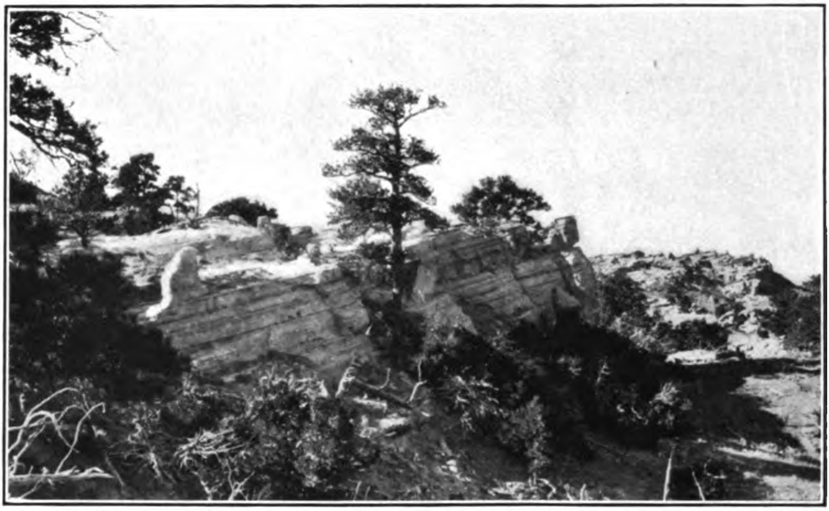
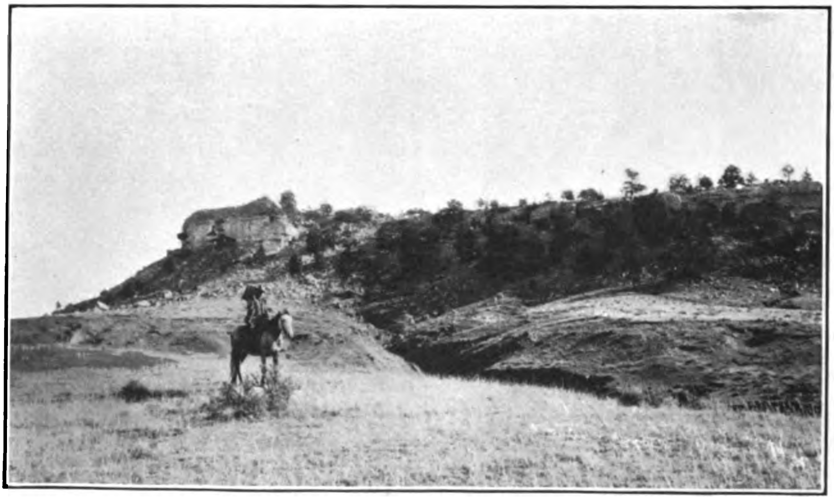
[a] Shaw, E. W., The Glenrock coal field, Wyoming: Bull. U. S. Geol. Survey No. 341, 1909, p. 154.

[b] Annals Carnegie Mus., vol. 6.



A. MASSIVE SANDSTONE AT BASE OF PARKMAN SANDSTONE MEMBER OF PIERRE FORMATION, SEC. 4, T. 38 N., R. 78 W.



B. LITTLE PINE RIDGE, SEC. 7, T. 38 N., R. 78 W.

M TOU

and the bed is not constant in thickness, being less than 14 inches over much of the field. An analysis of an air-dried sample is given below:

Analysis of an air-dried sample of coal from Little Pine Ridge, in NW. ¼ NW. ¼ sec. 32, T. 41 N., R. 78 W.

Proximate:	
Moisture	13.63
Volatile matter	32.61
Fixed carbon	38.19
Ash	15.57
Ultimate:	
Hydrogen	5.32
Carbon	50.81
Nitrogen	1.04
Oxygen	25.66
Sulphur	1.60
Ash	15.57
Calories	4,892
British thermal units	8,806

A collection of fossil leaves was obtained from the sandstone of Little Pine Ridge above the coal, but no invertebrate fossils were found. The sandstone of Little Pine Ridge has been traced through to North Platte River, where its coal was mapped and described by Shaw as "Coal A" in the report just cited.

Above the sandstone forming Little Pine Ridge is 600 feet of shale, containing some sandy beds. In these beds a few marine invertebrates were found.

Fox Hills sandstone.—Upon the shale just mentioned rests a sandstone about 100 feet thick, which is persistent throughout this general region. In some localities it is broken in its middle part by a bed of brown carbonaceous shale 6 feet thick. The sandstone below is brown and weathers characteristically into small knobs and pillars. The sandstone overlying the shale is pure white.

Above this sandstone is 600 feet of alternating sandstone and shale of marine origin. This is capped by a pure white sandstone 100 feet thick, which bears the marine plant *Halymenites* and is overlain by the fresh-water beds of the Lance formation. Associated with this sandstone are one or more coal beds, which, for the most part, are but a few inches thick, but which in certain places (as for example, sec. 6, T. 38 N., R. 77 W., and sec. 4, T. 37 N., R. 78 W.) reach a thickness of 5 feet or more. The lower limit of the Fox Hills sandstone is as yet uncertain and is here placed arbitrarily at the base of the sandstone described in the paragraph above. Further studies may, however, show that this boundary is placed too low in the section and that the name Fox Hills should be applied to the upper part of the sandy series only instead of to the whole.

CRETACEOUS OR TERTIARY SYSTEM.

Lance formation.—Above the Fox Hills sandstone are 50 feet of transitional beds—shale, sandstone, and thin coal—which are barren of fossils. Above these comes the concretionary buff sandstone of the Lance formation (also known as "Ceratops beds" and "somber beds") bearing the bones of *Triceratops* and *Trachodon.* The Lance formation is 3,200 feet in thickness and is overlain by the Fort Union formation, comprising the youngest strata exposed in this region.

TERTIARY SYSTEM (EOCENE SERIES).

Fort Union formation.—At the base of the Fort Union formation lies approximately 2,000 feet of white shaly sandstone containing here and there red ferruginous beds. The sandstone in this area forms a prominent pine-covered ridge which can be seen for many miles. Above the sandstone occur one or more coal beds and above them a great series of sandstone and shale for the most part light in color. The whole formation is 4,500 feet in thickness.

FOSSILS.

The small letters before the collections refer to locations on the general map. These locations are not to be taken as precise, except those accompanied on the map by a small triangle, the symbol for an instrumental location.

The fossil plants named below were identified by F. H. Knowlton, of the United States Geological Survey:

a. Shells and seaweed from lower part of Parkman sandstone member, 1 mile east of Shannon.
    Halymenites major Lesq.

b. Northwest corner T. 41 N., R. 78 W., 6 miles north of Shannon, near base of Lance formation.
    Platanus cf. *P. raynoldsii* Newb.
    Salix? sp.?

This material is too poor to say much about, as there are no margins preserved, but so far as can be made out it suggests only the "somber beds."

The following invertebrate fossils were collected by R. W. Stone and identified by Dr. T. W. Stanton of the United States Geological Survey:

c. One-third mile east of Shannon, in bed coulee. Upper part of dark shale below Parkman sandstone member.
    Inoceramus cripsi var. barabini Morton.
    Nucula sp.
    Lucina? sp.
    Protocardia subquadrata E. and S.?
    Baculites ovatus Say.

These belong to the Montana group fauna.

d. Coulee one-third mile east of Shannon. Upper part of dark shale below Parkman sandstone member.

Inoceramus cripsi var. barabini Morton.
Baculites ovatus Say.

Same horizon as *c*.

e. Top of shale below Parkman sandstone member, three-fourths mile east of Shannon.

Inoceramus cripsi var. barabini Morton.
Baculites ovatus Say.
Scaphites nodosus Owen.

Montana.

f. Upper part of dark carbonaceous series, about 150 feet above massive sandstone of the Parkman member, 1 mile northeast of Shannon.

Ostrea patina M. and H.?
Veniella sp.
Sphæriola cordata M. and H.
Liopistha undata M. and H.
Dentalium sp.
Fasciolaria? sp.

f. Float from same locality and horizon as *f*, 30 feet above limonite band in Parkman sandstone member and below bone horizon.

Avicula linguiformis E. and S.
Avicula nebrascana E. and S.
Syncyclonema sp.
Leptosolen sp.
Liopistha undata M. and H.
Baculites ovatus Say.
Baculites compressus Say.
Pachydiscus complexus (H. and M.)

The last two lots belong to a phase of the Montana fauna that is very similar to that which occurs in the Parkman sandstone of northern Wyoming, the upper Claggett near Billings, Mont., and the Mesaverde formation of the Laramie Plains near Harper, Wyo. It is believed that about the same horizon is represented at all of these places.

g. Limestone at top of shale below Parkman sandstone member, 1 mile northwest of Shannon.

Inoceramus cripsi var. barabini Morton.
Mactra sp.
Baculites compressus Say.

Montana.

g. Yellow sandy series, 15 feet above collection *g* and about 75 feet below massive sandstone of the Parkman member, one-half mile northwest of Shannon.

Lingula sp.
Callista deweyi M. and H.?
Mactra sp.
Baculites compressus Say.

Montana.

h. Base of Parkman sandstone member, 1½ miles north of Shannon, west of Salt Creek.

Avicula nebrascana E. and S.
Cardium speciosum M. and H.
Tellina? sp.

Leptosolen sp.
Corbulamella gregaria M. and H.
Liopistha undata M. and H.
Same fauna as *f*.

i. 1¼ miles north of Shannon, in east bank of Salt Creek. Same horizon as *f*.
Ostrea sp.
Avicula nebrascana E. and S.
Pinna sp.
Veniella subtumida M. and H.
Liopistha undata M. and H.
Anchura sp.
Fasciolaria? sp.
Pyrifusus? sp.
Pyropsis? sp.

j. About 3 miles southeast of Shannon, above Parkman sandstone member.
Callista deweyi M. and H.
Baculites ovatus Say.
Scaphites sp. related to S. nicollettii (Morton).
Upper Montana.

a. 1 mile east of Shannon, in lower part of Parkman sandstone member.
Inoceramus cripsi var. barabini Morton.
Sphæriola sp.
Cardium speciosum M. and H.
Liopistha undata M. and H.
Mactra formosa M. and H.
Lunatia sp.
Same fauna as *f*.

k. Same horizon as collection *f*, 1½ miles east of Shannon.
Modiola attenuata M. and H.
Veniella subtumida M. and H.
Liopistha undata Say.
Dentalium sp.
Anchura sp.
Fasciolaria sp.
Baculites ovatus Say.
Same fauna as *f*.

l. 2 miles east of Shannon and 105 feet above Little Pine Ridge.
Mactra gracilis M. and H.
Baculites compressus Say.
Montana.

m. 2 miles east of Shannon, 95 feet above *l*.
Leda scitula M. and H.
Thracia sp.
Corbula sp.
Mactra gracilis M. and H.
Scaphites nodosus Owen.
Crustacea—undetermined fragments.
Montana.

n. 3 or 4 miles east of Shannon, in bank of Sherwood Creek.
Protocardia subquadrata E. and S.
Dentalium sp.
Montana.

o. 2¾ miles southeast of Shannon below Parkman sandstone member.

Inoceramus.

Baculites ovatus Say.

Montana.

p. Just west of S. ¼ corner sec. 10, T. 40 N., R. 78 W., in middle zone of large gray sandstone ledges several hundred feet below the top of the Fox Hills sandstone.

Inoceramus simpsoni Meek?

Upper Montana.

q. Shale in bank of Salt Creek, one-fourth mile south of Shannon.

Inoceramus cripsi var. barabini Morton.

Mactra sp.

Baculites anceps var. obtusus Meek.

Montana.

r. T. 38 N., R. 78 W., at station marked 5588, north-central part of township.

Pachydiscus complexus (H. and M.)?

The type of the species was found in the Pierre shale on Missouri River, in South Dakota. The species or a closely allied form also occurs in the Mesaverde formation near Harper, Wyo.

Near east side sec. 18, T. 40 N., R. 77 W.

Unio sp. cast.

Anodonta parallela White?

Sphærium sp.

Planorbis sp.

Physa sp.

Linnæa? sp.

Helix? sp.

Acroloxus sp. related to A. minutus M. and H.

Viviparus sp.

Viviparus trochiformis M. and H.? possibly young of Tulotoma thompsoni White.

Goniobasis tenuicarinata M. and H.?

This lot does not contain any strictly diagnostic species that can be positively identified. It may belong either to the Lance formation or to the Fort Union formation.

Powder River oil field. The Wall Creek standstone lentil, above road east of Wall Creek.

Inoceramus sp. Fragments.

Prionocyclus wyomingensis Meek.

Colorado group, near the horizon of the top of the Benton shale.

Vertebrate fossils identified by C. W. Gilmore and J. W. Gidley, U. S. National Museum.

f. 270 feet above the base of the Parkman sandstone member, 1 mile east of Shannon. Collected by Stone.

Caudal vertebræ of Trachodon.

Other pieces of dinosaur bones which were too fragmentary to be identified.

Sec. 4, T. 42 N., R. 79 W. Top of bluff east side Salt Creek. Collected by Stone.

Portions of the frill of Triceratops.

Foot bones and part of jaw of Trachodon.

Foot bone of some carnivorous dinosaur.

Fragmentary turtle remains, not determinable.

o. With Baculites ovatus, Inoceramus, etc., 2¾ miles southeast of Shannon. Collected by Stone.
Vertebral centrum of Mosasaurus.

s. SE. ¼ NW. ¼ sec. 13, T. 40 N., R. 78 W.; collected by Howell.
Fragment of dinosaur bone. Not determinable.

t. Sec. 27, T. 40 N., R. 79 W.
Conglomerates containing fish teeth representing the genera Carcharias, Lamna, and Galeocerdo.

u. SW. ¼ SE. ¼ sec. 23, T. 41 N., R. 79 W.; collected by Howell.
Dermal scute of a large crocodilian recently described by W. J. Holland (Annals Carnegie Mus., vol. 6, No. 1, pp. 281–294) as Dinosuchus hatcheri. The type of the above genus and species is from the Judith River formation of Montana.

v. SE. ¼ SE. ¼ sec. 25, T. 41 N., R. 78 W.; collected by Mulholland.
Claw of one of the carnivorous dinosaurs, probably Ornithomimus. This genus is also present in the Judith River formation.

STRUCTURE.

SALT CREEK ANTICLINE.

The Salt Creek anticline, considered as a whole, is an arch of strata about 18 miles long by 6 or 8 miles wide, trending in general northwest-southeast. On the northeast slope the dip of the rocks ranges from 8° to 10°, but on the southwest slope it is considerably steeper, ranging from 15° to 29°. At each end of its axis the anticline pitches downward with gradually decreasing dip until it vanishes entirely.

When considered in detail the anticline is seen to consist of two distinct domes, the northern or principal dome, on which the discoveries of oil have been made and which is outlined by the Shannon sandstone lentil, and the southern or smaller dome, in which the Shannon sandstone is beneath the surface and which is partly outlined by the Parkman sandstone member. In the following description the term " Salt Creek dome " will be applied to the northern of these two structures and " Teapot dome " to the southern. The two domes are separated by a shallow syncline, the axis of which lies just northwest of and parallel to Teapot Creek near its mouth.

The axis of the anticline at its north end appears to lie just east of well No. 7 at Shannon. Thence it runs a little west of south to the point where Salt Creek crosses the Shannon sandstone lentil on emerging from the dome. Continuing its course it bends a little to the west, passing west of Dutch well No. 1, and then turns south, crossing the western borders of secs. 26 and 35, T. 40 N., R. 79 W. It then turns rather abruptly to the east and southeast to a point on the Shannon sandstone in sec. 18, T. 39 N., R. 78 W., about one-half mile east of the place where the Casper road crosses that stratum. This abrupt turn to the east is marked by a number of faults, and the precise position of the axis is difficult to determine. It runs, however, in a course approximately S. 34° E., to the middle of the southern line of T. 39 N., R. 78 W., which it crosses about halfway between Little Teapot Creek on the east and the escarpment of Parkman sandstone on the west. Thence the course of the axis swings gradually to the south, approaching Little Teapot Creek, until at the south end of the anticline it practically coincides with the course of that stream.

It is evident that throughout the greater portion of its course the axis is nearer the western side of the anticline than the eastern, a condition which follows naturally from the fact that the dips are steeper on the western than on the eastern limb.

A better idea of the general structure and the position of the axis of the anticline may be had from a study of the structure contours on the map than can be gained from a written description. As has been already stated (p. 41), the present relief is not directly indicative of the structure; the axis of the anticline is not marked in the field by a ridge, in fact it is in part occupied by a stream valley. The strata which originally extended over the arch have been largely removed by erosion which has left only their truncated edges encircling the dome. The Shannon sandstone lentil, had it not been so removed, would be 900 feet above the present surface at Dutch well No. 1.

SALT CREEK DOME.

GENERAL CHARACTER.

The Salt Creek dome is an oval structure about 10 miles long and 5 or 6 miles wide. Its general shape is well shown by the outcrop of the Shannon sandstone lentil. (See also structure contours and cross sections shown on large map, Pl. VII.) The general structure of the dome within the encircling outcrop of the Shannon sandstone has been worked out from dip and strike determinations made for the most part on thin reddish brown calcareous layers, in places less than an inch thick, which are present in the shale. Where these are absent dip and strike readings are hard to obtain. As already stated, the axis of the dome lies much nearer the west than the east side of the oval. The highest point on the axis lies somewhere in the SW. ¼ sec. 26 or the NW. ¼ sec. 35, T. 40 N., R. 79 W. The axis in this locality is well defined, for the crest of the uplift is only a few rods wide, and the rocks on the sides dip away at perceptible angles to the east and to the west. A mile or more north of this point the crest begins gradually to broaden and the axis becomes less definite. Minor rolls occur on the surface of the dome. Near the oil seeps, in the central part of sec. 11, T. 40 N., R. 79 W., a sharp bend occurs, as is indicated by the abrupt change in dip from 7° to 12° without change in strike. It seems not unlikely that the oil seeps may in some way depend on this bend. Near Shannon, at the extreme north end of the dome, the crest of the fold becomes abruptly narrower and the western limb has a much steeper dip than the eastern. Several faults may be observed along the escarpment of the Parkman sandstone, to the east. How far they extend toward the wells, however, is a matter of conjecture, as they are difficult to detect in the soft shale. The wells near Shannon, with the exception of No. 8, are located on the steeper western limb of the fold.

Considering now the southern portion of the Salt Creek dome, the crest south of the highest point of the fold broadens and the axis turns eastward. Along Castle Creek, especially on its east side, it is impossible to make many satisfactory determinations of strike and dip owing to the lack of exposures, but it is probable that considerable irregularity in structure in this area.

FAULTS IN THE SALT CREEK DOME.

Faults occur in many places in the tilted strata of the Salt Creek anticline. Displacements in the comparatively hard sandstone beds, such as the Shannon sandstone lentil and the Parkman sandstone member, which outcrop on the flanks of the dome, may be readily observed, but those that occur in areas occupied by shale, especially over the interior of the dome, are hard to detect, for the shale there includes no distinctive strata which are conspicuous enough topographically to show such breaks and the narrow planes of the faults are generally covered by the wash of the rains. Therefore the faults mapped as cutting the sandstone escarpments were nearly all observed, but those shown in the shale area within the dome have been inferred from an adjustment of the structure contours. In the southern part of the dome, for example, it is impossible to space the contours according to the dips and yet make them accord with the strikes observed in the field without introducing very sharp bends or faults. Several faults have therefore been inferred and are represented on the map. All inferred faults are indicated by question marks. These inferred displacements are probably continuations of faults observed in the Shannon sandstone to the east, and they are thus drawn.

The faults trend in general at right angles to the major axis of the anticline, the displacement ranging from 5 to over 100 feet. By far the greater number are normal faults, which are ordinarily considered to be due to tension, and in these the fault plane dips toward the downthrown side. Thrust faults, due to horizontal thrust, also occur, and in these the fault plane dips toward the upthrown side.

A typical normal fault, trending N. 78° E., occurs in the Shannon sandstone near the middle of sec. 5, T. 39 N., R. 78 W., just south of a high point which bears a monument of stones. This fault has a stratigraphic displacement of 128 feet and the fault plane dips to the southeast at an angle of 61°, the southeast side being downthrown.

The rocks immediately adjoining the fault are but little broken, the brecciated zone, which is marked by deposits of calcite, being only 10 or 12 inches wide. Another normal fault, trending N. 77° E., occurs in sec. 3, T. 39 N., R. 79 W. This fault has a displacement of 117 feet, the downthrow being on the southeast side. It is considerably too far north to be in line with the fault just described, on the opposite side of the dome, and the two are probably not connected across the anticline, yet no positive statement on this point can be made.

How far such faults may extend toward the center of the dome or to what depth they may reach below the surface it is impossible to say. Should they reach the Wall Creek sandstone lentil the throw is sufficient to interrupt the continuity of the sand. Faults in soft shale, however, abruptly disappear, owing to the plasticity of the strata, and it may be that those which appear to be of considerable size at the surface do not extend a great distance below it.

In many places a block of strata that lies between two faults is upthrown as a whole, such as the block between two small faults in the SW. ¼ NW. ¼ sec. 7, T. 40 N., R. 78 W. This block occurs on a local escarpment formed by a sandstone somewhat above the Shannon sandstone lentil.

A typical thrust fault occurs in the Shannon sandstone in the SE. ¼ NE. ¼ sec. 15, T. 40 N., R. 79 W. The stratigraphic displacement is 52 feet and the fault plane dips to the southwest, toward the upthrown side. On this side the sandstone has been thrust over the other for a horizontal distance of 80 feet.

At the south end of the Salt Creek dome, near the place where the Casper road crosses the Shannon sandstone, in sec. 18, T. 39 N., R. 78 W., and sec. 13, T. 39 N., R. 79 W., the sand is cut by an east-west fault that brings up a second escarpment of the Shannon sandstone south of the first. This is probably a thrust fault, the southern of the two ridges having been thrust upward and northward somewhat over the main mass of the sandstone. The dips do not show this, however, being no steeper on the southern ridge than on the northern. Exposures in this locality are so obscured that the exact structure is difficult to determine.

TEAPOT DOME.

The Teapot dome lies south of the Salt Creek dome and is separated from it by a shallow syncline whose axis forms a right angle to the axis of the anticline as a whole. The Teapot dome is somewhat smaller than the Salt Creek, being about 8 miles long by 4 miles broad. The Shannon sandstone disappears below the surface at the south end of the Salt Creek dome and does not come to the surface again in the Teapot dome, which is outlined by the Parkman sandstone member, the next prominent bed of sandstone above the Shannon sandstone lentil. Beyond this the higher sandstone of the Little Pine Ridge forms a second escarpment. The variation in the dip of the rocks about this dome is well shown by the variation in the distance between the outcrops of the two sandstones. On the east, where the dip is 10° or 12°, the distance between the outcrops is about three-quarters of a mile; at the southern extremity of the dome, where the axis pitches southward at an angle of 5°, the distance between the outcrops is a mile and a half; on the west, where the dip of the strata is as high as 24°, the distance between the sandstone escarpments is only a quarter of a mile. The Teapot dome differs from the Salt Creek dome in that its crest is divided by a slight cross fold or buckle, so that the dome really consists of two very small domes. The northern of these domes is somewhat the higher and probably brings the Shannon sandstone within 100 or 200 feet of the surface. The southern of these small domes is clearly defined in the field by two white beds of bentonite, on which dip readings can be taken. Over the dome as a whole exposures are not so numerous as in the Salt Creek dome and the structure, therefore, can not be worked out with so great accuracy.

No surface indications of oil were found in the Teapot dome, but an oil seep is reported in sec. 22, T. 38 N., R. 78 W. (See p. 67.)

GENERAL RELATIONS OF THE SALT CREEK ANTICLINE.

East of the Salt Creek anticline, for perhaps 10 or 12 miles from its crest, the rocks dip eastward at angles ranging from 5° to 10°. East of the escarpment of Big Pine Ridge these dips flatten rather abruptly in the rocks of the Great Plains which lie beyond, so that within 2 or 3 miles the strata become practically horizontal and remain so for 50 miles or more, until they begin to rise gradually toward the Black Hills uplift on the east.

West of the Salt Creek anticline the rocks plunge abruptly into a syncline, but rise again almost immediately in the long gentle slope of a second dome or anticline, about 15 miles wide, the axis of which lies a little east of the Tisdale ranch on Powder River. This dome is called the Powder River anticline. West of it lies a second syncline, beyond which the strata rise gradually on the flanks of the Bighorn Mountains. The Tisdale and Salt Creek anticlines are thus minor structures, distinct from the great anticlinal uplift of the Bighorns, yet doubtless connected with it in origin.

BOTHWELL SYNCLINE.

The syncline west of the Salt Creek anticline may be best considered as two synclines, the axis of one pitching north, that of the other pitching south, the two uniting just west of the highest point of the Salt Creek dome. As this point is much nearer to the northern extremity of the anticline, considered as a whole, than to its southern end, the southward pitching syncline is much the larger of the two, and by it the outcrop of the Parkman sandstone is carried far to the north in a great loop before it swings southward, away from the field.

The northern syncline is much shallower and rapidly dies out to the north, so that it exercises no appreciable effect on the trend or direction of the outcrop of the Parkman sandstone member.

POWDER RIVER ANTICLINE.

The Powder River anticline lies about 15 miles west of the Salt Creek anticline and is in many respects similar to it. It is outlined by the outcrop of the Wall Creek sandstone lentil, which lies about 1,970 feet below the Shannon sandstone lentil and which does not come to the surface in the Salt Creek field. In the Powder River anticline, as in the Salt Creek anticline, the dip of the eastern limb is gradual, whereas that of the western is abrupt.

The discoveries of oil, which here occurs in the Dakota sandstone, have been made along the crest of the arch near the western side of the dome. (For a description of this oil see p. 78.)

Any discussion of the forces that produced the Powder River and Salt Creek anticlines, as well as the uplift of the Bighorn Mountains themselves, must be for the most part theoretical. It seems probable, however, that the thrust that produced each was vertical (at the surface at least), since the shale, which is the predominating rock in the smaller structures, is not competent to transmit horizontal stresses for any considerable distance. The movements which caused these structures occurred, in part at least, after the deposition of the Fort Union, for the rocks of that formation are tilted around the margins of these uplifts.

STRUCTURE CONTOURS.

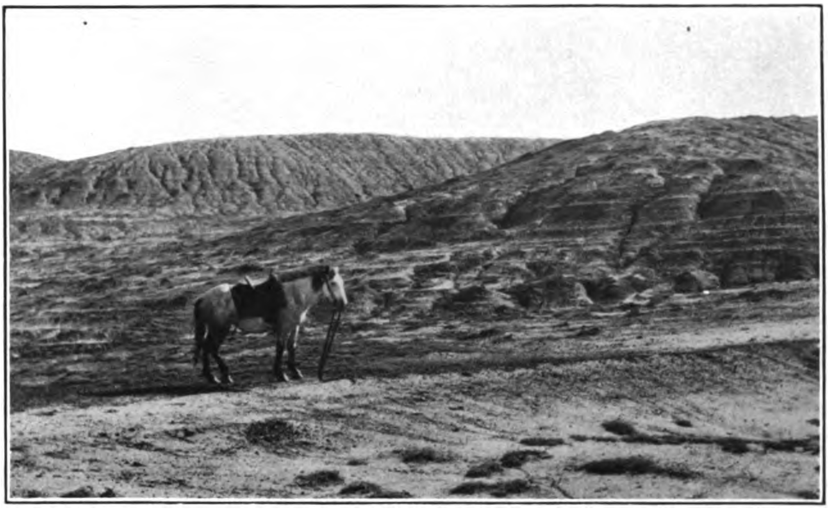
The structure of the Salt Creek anticline is represented on the map (Pl. VII, in pocket) by structure contours drawn on the upper surface of the lowermost bed of the Shannon sandstone lentil. This stratum was chosen as a datum horizon because the oil at Shannon occurs in or just below it. The contours represent the anticlines and synclines formed by the warping of the Shannon sandstone as they would exist had they not been partly destroyed by erosion. These contours have no relation whatever to the present topography, but have been determined by means of surface altitudes at numerous points on the Shannon sandstone and off it, by dip and strike readings, by stratigraphic distances between prominent beds of sandstone, and by well records. The altitudes were calculated from an assumed datum of 5,000 feet above sea level (see p. 64), and contain no error in amount exceeding 10 feet. Their relative values only are important.

The starting points selected in plotting these structure contours were points of known altitude on the Shannon sandstone—either surface outcrops or places at which the sandstone had been penetrated by wells. In the latter case, the depth of the well and altitude of the surface being known, the altitude of the top of the sandstone was easily calculated.

The Parkman sandstone member is the important key rock above the datum surface, but before it could be used in determining the positions of structure contours on the Shannon sandstone it was necessary to determine as accurately as possible the distance between the two sandstones. This distance was found by measuring accurately the distance between their outcrops and then calculating from observed dips the stratigraphic distance between the beds. This calculation was often done graphically, the dips being plotted and the distances between the beds scaled off. The distance thus determined between the Shannon sandstone lentil and the Parkman sandstone member at three separate points was 1,300, 1,300, and 1,440 feet, an average of nearly 1,350 feet. The altitude of the Shannon sandstone at any given point below an outcrop of the Parkman sandstone was therefore obtained by subtracting 1,350 feet from the surface altitude of the base of the Parkman outcrop.

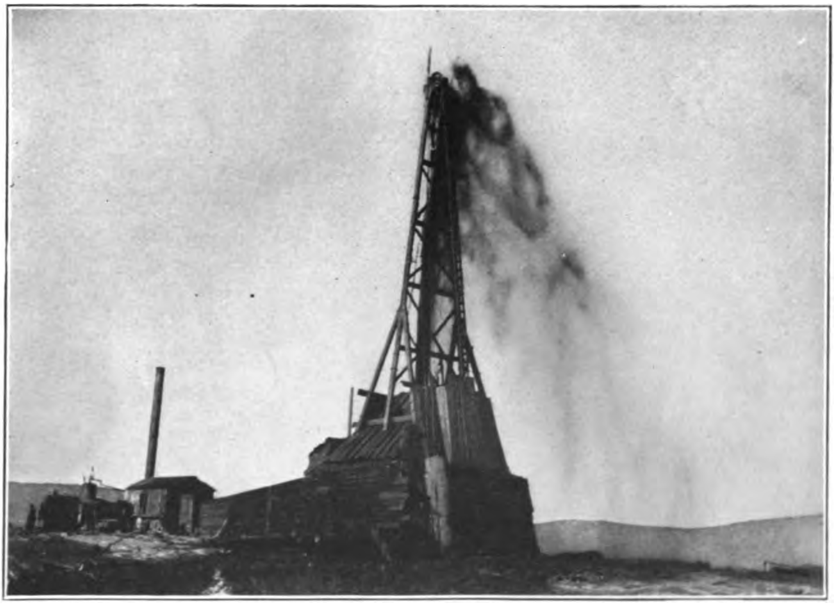
The altitude of the Shannon sandstone lentil was thus obtained at many points outside the actual outcrop of that stratum—in fact, in a belt corresponding to the outcrop of the Parkman sandstone member. The contours were then spaced between the sandstone outcrops according to the dips. If a bed dips 5° it falls 100 feet in a certain horizontal distance. If it dips 10° it falls 100 feet in a much shorter distance. A scale for any contour interval which materially aids in the work may be constructed according to the formula $x=\frac{b}{\tan a}$, where x is the horizontal distance in feet between contours, b the contour interval, and a the angle of dip.

Within the outcrop of the Shannon sandstone the compilation of structure contours is much more difficult, as shale is generally the surface rock and there is no easily recognized stratum which, traced from point to point, will serve as a marker in the stratigraphic section. Fortunately, the bedding in the shale is generally well marked by thin beds of ferruginous shale, as shown in Plate X, *A*, and from dip readings on these the shape of the dome was determined with a fair degree of accuracy. Many observations of strike and dip were made, the point of observation being located horizontally by inter-



A. SHALE OF THE PIERRE FORMATION IN THE SALT CREEK ANTICLINE, SEC. 35, T. 40 N., R. 79 W.

Showing thin ferruginous layers on which dip readings were taken.



B. A FLOW AT DUTCH NO. 1, DECEMBER 1908, BEFORE WELL WAS CAPPED.

U of M

section from known points, and in many places vertically by dip angle readings taken with the telescopic alidade.

The determination of the structure from such data was necessarily difficult and somewhat uncertain, but the contours were extended inward from the Shannon sandstone rim in much the same manner as they were determined between the Shannon sandstone lentil and the Parkman sandstone member. The final check was the agreement of the contouring brought in from the rim rock from various directions. This agreement was so close that the amount of error in the contours and the height of the dome is thought to be negligible.

It is evident that the structure contours must be parallel to the lines of strike. In some areas in order to space the contours according to several dip readings and at the same time make them conform to the several strikes given an abrupt bend in the contours is necessary. This may indicate an actual bend of the strata or a fault which was not observed in the field work. Faults in shale may be difficult to detect.

The structure contour map just described is obviously far from perfect, but is believed to be the best representation of the real conditions that can be made from the facts at hand. The map can be employed for various purposes, but it should be used with discretion. It shows approximately the depth of the Shannon sandstone or any sandstone at any point where the surface altitude is known. For example, if the surface altitude at a particular point is 4,750 feet and the point falls on the map between contours 3,900 and 4,000 it is evident that the Shannon sandstone is 4,750—3,950=800 feet below the surface at this point. The most important use to which the map can be put is to determine the position at any particular point of the oil-bearing Wall Creek sandstone lentil, the important sand of the field. It is assumed that the Wall Creek sandstone is parallel with the Shannon sandstone and that it is deformed and crumpled in a similar manner, and in the absence of any evidence of unconformity between them this assumption seems to be perfectly justifiable.

The first step in calculating the depth of the Wall Creek sandstone at any point is to determine the distance between this sand and the Shannon. The Wall Creek sandstone is not exposed in the Salt Creek field, but has at the present time been reached in several wells. When this survey was undertaken only one well, Dutch No. 1, had reached the sand. It was necessary to calculate the thickness of strata exposed between the mouth of this well and the outcrop of the Shannon sandstone on the west and to this thickness to add the depth to the sand as observed in Dutch No. 1, the sum being the distance between the two sands. The work was done by tracing certain thin reddish layers in the shale around the dome to a point from which a continuous series of dip readings could be taken to the outcrop of the Shannon sandstone on the west. Surface elevations were also taken at numerous points. The distance between the sands as thus calculated was 1,950 feet. Recently a well has been drilled by the Franco company in the SW. ¼ SW. ¼ sec. 18, T. 40 N., R. 78 W., which struck the Wall Creek sandstone at a depth of 1,760 feet. The well is so near the outcrop of the Shannon sandstone that it is a simple matter to measure the thickness of beds exposed between the mouth of the well and the base of the sand, and from this thickness and the measurements in the well to determine accurately the thickness of strata between the two sands, which is 1,970 feet. This determination serves also as a check on the former work.

To estimate the depth of the Wall Creek sandstone at any point the altitude of the Shannon sandstone at that point must first be obtained from the structure contours on the map. Suppose this altitude to be 5,600 feet; since the Wall Creek is 1,950 feet below the Shannon, the elevation above sea level of the Wall Creek at the required point is 3,650 feet. If the surface altitude is 4,900 feet the actual depth of the Wall Creek sandstone at the required point is 1,250 feet. If the dip of the rocks is steep this number should be multiplied by the cosine of the angle of dip. In this area the dips are generally low and for most places this correction need not be made.

The cross sections of the field, which appear on the margins of the general map, were drawn from the structure contours. The Shannon sandstone was first outlined and the other strata were drawn parallel to it at proper distances. The vertical scale is not exaggerated.

METHODS OF FIELD WORK.

HORIZONTAL CONTROL.

In the present study mapping was done on a scale of 2 inches to the mile, the unit of area being the township. A 15-inch plane table and a telescopic alidade were employed. A base line was measured in sec. 13, T. 40 N., R. 79 W. Two intervisible points were chosen on level ground, one in the NE. ¼ NE. ¼ sec. 13 and the other in the SW. ¼ SW. ¼ of the same section. The distance between them, 5,500 feet, was measured with a 50-foot tape. The plane table was set up at the southwest end of the base line and the approximate magnetic declination of 16° 30′, obtained from the Land Office plat, was laid off on the sheet. A compass was then placed along this line and the table was oriented by it. By pacing from a near-by section corner a point on the sheet for this end of the base line was so fixed that the map of the township when finally completed would fall so evenly on the sheet that a proper margin would be left on all sides. A fine needle was stuck in the sheet at the point chosen and by placing the ruler edge of the alidade against it and sighting at the other end of the base line a line was drawn on the sheet to represent this direction. The distance, 5,500 feet, was then scaled off along this line and a point was thus established which represented the other end of the base line. Other sights were taken to prominent points, such as the hill in the SE. ¼ SE. ¼ sec. 23, the point of the rim rock just south of the northeast end of the base line, and the flat-topped hill in the eastern part of sec. 14. On these hills were placed white flags or monuments of stone 2 to 4 feet high which furnished definite and easily recognizable points at which sights could be taken.

The plane table was next removed to the northeast end of the base line and oriented by a backsight on the first location. Sights were then taken to the prominent points already sighted from the first station and their locations were thus determined by intersection. These points being occupied, other points were in turn located from them and the system of triangulation was expanded to cover the township. During this work orientation was made by backsighting to some point previously occupied.

After the main control was established the compass was used in orientation, and where possible this was checked by intersection from three points. If the intersection was not perfect the table was shifted slightly one way or the other until the three lines met in a point. Locations of section corners, dip readings, outcrops, and the like were usually made in this way, other points being cut in by intersection.

When work was to be begun in T. 40 N., R. 78 W., two located points were chosen near the eastern margin of the sheet of T. 40 N., R. 79 W., to serve as a base line for the new township. Of these the northeast end of the first base line was one and a high point located north of the center of sec. 6, T. 40 N., R. 78 W., was the other. The eastern margin of the old sheet was placed over the western margin of the new sheet and the two points were pricked through with a needle. These points served as the ends of a new base line, and control was expanded over this township exactly as in the other one. Control was carried over townships to the north and west in a similar way.

A slight error appeared in the control in the southern part of T. 40 N., R. 79 W., so that when work was begun in T. 39 N., R. 79 W., it was considered advisable to measure a new base line. The southeast corner of sec. 1, T. 39 N., R. 79 W., was chosen for the northeast end of this base line and a flag was set to mark it. For the southwest end of the line a monument of stone was built on the ridge north of the center of sec. 13, T. 39 N., R. 79 W. The distance between these points was measured as 7,220 feet. From this base line control was established over T. 39 N., R. 79 W., and T. 39 N., R. 78 W., and from these townships it was carried south and west by the transfer of established points as described in the case of T. 40 N., R. 78 W.

Points common to any two adjoining sheets were thus fixed and by means of these points the sheets could later be joined together in proper relation to each other.

VERTICAL CONTROL.

The altitude above sea level at Casper, 50 miles south of the field, has been determined. Elevations have been carried from Casper to Shannon by barometer and thus the approximate altitude at Shannon was known. Relative elevations only were important in the present study, and it was decided to assume the altitude of some prominent point and from this to calculate altitudes throughout the field. For this purpose the prominent hill south of Dutch well No. 1, in the SE. ¼ SE. ¼ sec. 23, T. 40 N., R. 79 W., was chosen, and its highest point was assumed to be 5,000 feet above sea level. A white flag was set up on the hill and readings were taken at the base of the pole.[a]

LAND SURVEYS.

As already stated, the locations of section corners were determined by triangulation from control points. The errors in the land surveys are thus correctly represented as accurately as the scale of the map will permit. The original land corners which were found are represented on the map by a special symbol. It was impossible in the time allotted to the work to make careful search for every corner in the field. The endeavor was made, however, to locate most of the original corners on the Salt Creek dome and to locate a sufficient number over the rest of the area for the projection of the land net. In certain townships, as in T. 41 N., R. 78 W., only a small number of corners could be found, as the original surveys appear to have been defective. In T. 38 N., R. 78 W., and T. 38 N., R. 79 W., and in the portions of townships represented in R. 80 W. no search whatever was made for corners.

In drawing the land net on the map both solid and dotted lines have been employed—solid lines where the corners have been accurately determined, dotted lines where corners were not found and the land net is more or less theoretical.

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[a] Altitudes have recently been carried by vertical angles with the telescopic alidade from a United States Geological Survey bench mark west of Trabing, 40 miles north of the field. Such elevations are accurate within 10 or 15 feet. They indicate that the elevation assumed was 54 feet too low. Hence to obtain elevations above sea level add 54 feet to the elevations as given on the large map.

THE OIL SANDS.

SHANNON SANDSTONE LENTIL.

CHARACTER AND THICKNESS.

The Shannon sandstone lentil or rim rock has already been referred to as that which outlines the Salt Creek anticline and furnishes the oil obtained in the wells at Shannon. A good exposure of the sandstone occurs near the head of a draw in the SW. ¼ NW. ¼ sec. 12, T. 40 N., R. 79 W. The section is as follows:

Section of Shannon sandstone lentil in gulch in sec. 12, T. 40 N., R. 79 W.

	Feet.
Sandstone:	
Hard, reddish	4
Soft	7
Hard, buff	4
Fine-grained, white	80
Hard, buff	4
Soft	8
Hard	4
Fine-grained	26
Hard	4
Coarse, bluish, soft	30
Coarse-grained, saturated with oil	8
Shale.	
	179

In the above section the hard beds of sandstone form ledges as shown in Plate XI, *A*. These really fall into two groups, between which lies 80 feet of fine-grained shaly sandstone, so that from a distance the escarpment of the rim rock appears to be composed of two ledges. It must not be inferred that the thicknesses of the numerous hard beds are constant from place to place, yet the total thickness of the sandstone appears to be fairly constant throughout the field. The occurrence of the two hard beds in the Shannon sandstone agrees with conditions encountered in the Shannon oil wells. W. H. Smith states that on the flat near Shannon three sands were passed through in drilling, the first being doubtless the sandstone locally developed about 500 feet above the Shannon sandstone and outcropping on the east side of Salt Creek, southeast of the wells. The Shannon sandstone lentil itself was represented by two sands, about 30 feet apart, the upper bearing water and the lower oil. In well No. 8 these sands are reported as one. In this well water was struck at the top, and oil at a depth of 55 feet in the sand. The sand between the water and oil-bearing zones is very fine-grained.

In the 8 feet of oil-saturated sand at the base of the section cross bedding is marked. The sand is coarse and contains many dark minerals. At its base it is massive, but most of the layers are not more than 8 or 10 inches thick. It includes numerous calcareous and siliceous lenses. In the bed of Salt Creek, where it crosses the rim rock at the north end of the dome, two ledges of sandstone are exposed, which appear to correspond to the ledges 60 feet above the oil sand in the section. Mr. H. W. Davis states that he has seen oil standing here in pools, but at present there is no indication of oil at this place.

At about the center of sec. 12 of the same township about 2 square feet of the surface of the lower of the sandstone ledges, which here forms the rim rock, was oil-stained, but no trace of oil could be seen at any other place in the vicinity.

In the NW. ¼ SE. ¼ sec. 11 of the same township a sandstone saturated with oil occurs, which is taken to be the same bed as at the head of the gulch first described.

Just west of this point two oil seeps occur in the NE. ¼ SW. ¼ sec. 11. The southern seep is at the outcrop of the oil sand, but the northern is in shale. The oil probably rises through the shale from the oil sand below.

In the SW. ¼ SW. ¼ sec. 11 the oil sand is exposed, with the following section:

Section of Shannon sandstone lentil in sec. 11, T. 40 N., R. 79 W.

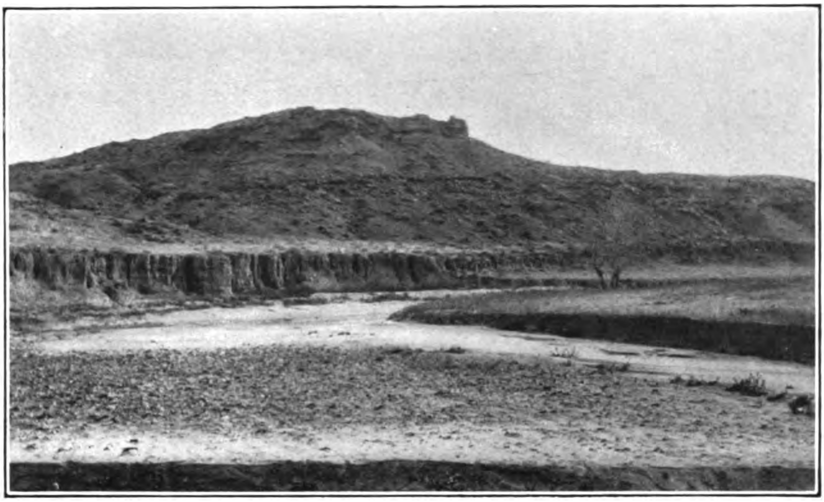
	Feet.
Sandstone bearing oil, top concealed	3
Shale, blue	5
Sandstone, saturated with oil	5
Sandstone, oil-stained	4
Shale, dark, water-bearing.	
	17

No other indications of oil have been found along the outcrop of the Shannon sandstone or rim rock in the Salt Creek anticline. Farther south, on the west limb of the anticline, the rim rock is made up of two hard beds with softer sandstone between, but no third bed bearing oil appears below them.

On the east limb of the anticline the conditions are much the same. Near the center of sec. 5, T. 39 N., R. 78 W., the following section of the rim rock was measured:

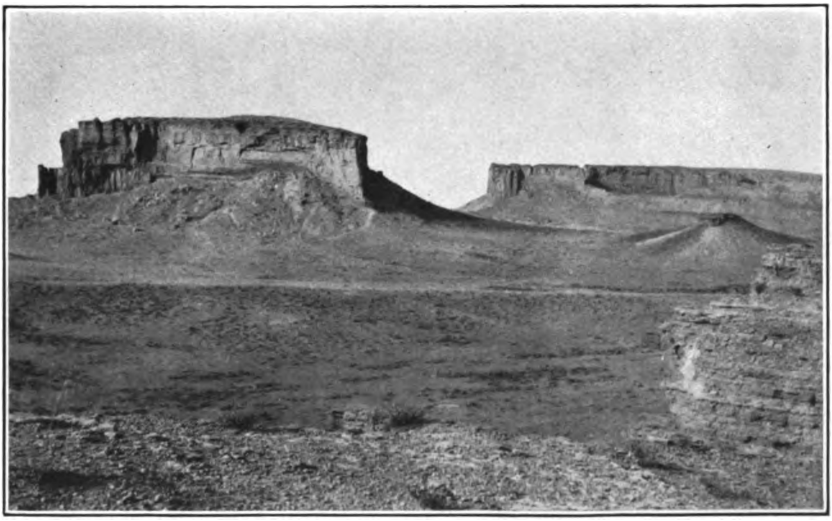
Section of Shannon sandstone lentil in sec. 5, T. 39 N., R. 78 W.

	Feet.
Sandstone, gray, weathering buff; the cap rock of the great butte and the "castles"	48
Sandstone, yellow and brown, weathering bluish; does not form a ledge	42
Sandstone, gray, weathering buff, fairly coarse; lower bed of the rim rock	48
Shale, bluish-black; upper part sandy; contains particles of biotite; base not exposed.	
	138



A. THE SHANNON SANDSTONE LENTIL, 1½ MILES SOUTH OF SHANNON, EAST SIDE OF SALT CREEK.

Both ledges appear, the upper at the crest of the hill, the lower, which carries the oil, half way down the slope. The cut bank above the creek is alluvium.



B. CASTLE ROCK. SHANNON SANDSTONE LENTIL. SW. ¼ SEC. 8, T. 39 N., R. 78 W.

The two ledges here stand in a single cliff.

It will be noted that although the sandstone here forms a higher, more conspicuous cliff than at the northern end of the anticline, it is in reality somewhat thinner—138 feet, as compared with 179 feet (see section on p. 65). The increased height of the cliff may be due in part to the slight dip of the rocks at this locality, which makes them less susceptible to erosion here than at the north end of the dome, where the dips are greater.

One mile south of the point just described, in the east-central part of sec. 8, T. 39 N., R. 78 W., the following section of the rim rock was measured:

Section of Shannon sandstone lentil in sec. 8, T. 39 N., R. 78 W.

	Feet.
Sandstone, hard, containing several thin, reddish calcareous layers; forms a ledge	52
Sandstone, soft; does not form a ledge	32
Sandstone, reddish	2
Sandstone, hard, corresponds to lower bed of rim rock	34
Shale, dark, lower limit not exposed.	
	120

The lower sandstone bed is not conspicuous here, the rim rock standing for the most part in one perpendicular cliff, as shown in Plate XI, *B*. One-half mile south of this point the upper sandstone appears as two hard ledges about 20 feet apart, with soft sandstone between them.

A letter recently received from Mr. Thomas S. Harrison, formerly of the Land Office, who spent a short time in the Salt Creek field, describes an oil seep in the NE. ¼ SW. ¼ sec. 22, T. 38 N., R. 78 W. The seep occurs in the bed of a stream near a sheep corral.

Mr. Harrison writes:

> Several springs of water came from the banks here, all alkaline, and the surface of the water and the ground showed oil. These springs came from the Parkman, and I took it that the oil was brought from the Pierre shale below, through one of the small faults which cross the anticline.

The seep thus described is at a considerable distance from any other known occurrence of oil, and is particularly interesting as indicating the possible existence of oil in the southern extension of the anticline.[a]

West of the Salt Creek anticline, as already mentioned, the Shannon sandstone plunges abruptly into a syncline, with dips ranging as high as 29°, but quickly rises again at very low angles and comes to the surface in a ridge having a general north-south course, about 3 miles west of the point where it disappeared. The ridge varies considerably in topographic expression from north to south, owing to differences in hardness and thickness of the sandstone. Across the eastern side of T. 41 N., R. 80 W., and the western side of T. 41 N., R. 79 W., the outcrop of the Shannon sandstone is represented by a low ridge along which the sandstone is here and there exposed. In the NW. ¼ sec. 30, T. 41 N., R. 79 W., water charged with hydrogen sulphide (H_2S) comes to the surface along a fault plane, forming a sulphur spring. A few rods south of this spring, in an exposure of the rim rock, about 5 inches of sandstone stained with oil was found. The stain is about 32 feet below the top of the sandstone ledge, as here exposed, and but a few feet above the underlying shale.

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[a] The writer recently visited this locality but was unable to discover any sign of the oil described by Mr. Harrison.

In the NE. ¼ sec. 31, in the bed of a deep coulee near the road, is an outcrop of the Shannon sandstone, which is said to give off the odor of petroleum. No indication of oil was seen here, however.

The ridge that marks the outcrop of the Shannon sandstone becomes more prominent southward until, in sec. 24, T. 40 N., R. 80 W., the sandstone begins to appear in ledges. In sec. 36 of the same township the sandstone forms perpendicular cliffs which are marked features of the landscape. These cliffs increase in height across the township to the south (T. 39 N., R. 80 W.). The escarpment faces west, the slope on the east being a dip slope of 3° or 4°.

No other indications of oil besides that above mentioned were found along this outcrop of the Shannon sandstone.

WELLS THAT OBTAIN OIL FROM THE SHANNON SAND.

THE FRANCO-AMERICAN COMPANY'S WELLS.[a]

The wells which obtain oil from the Shannon sandstone lentil are scattered over an area of a little more than a quarter of a square mile lying along Salt Creek in the northeast corner of T. 40 N., R. 79 W., and the southeast corner of T. 41 N., R. 79 W., as shown on Plate XII. They belong to the Franco-American Company. A brief description of each well is here given. The author is indebted to W. H. Smith, of Casper, for much of the information. All the wells except No. 2 are in the vicinity of Shannon.

1. Drilled in 1889. Altitude of top of casing, 4,755 feet; depth, 1,030 feet. Struck oil at about 1,000 feet. From 1895 to 1904 this well was pumped almost daily, yielding an average of 3½ barrels of oil a day, and its yield did not decrease during that time.

2. Well drilled at the junction of Teapot and Salt creeks, 10 miles southeast of Shannon. Record lost. Flows alkaline water.

3. Altitude of top of casing 4,752 feet; depth, 1,196 feet. No oil. The well flows a 1-inch stream of water, which is slightly alkaline and gives off a faint odor of H_2S. Well was not cased, but water is supposed to come from the Shannon oil sand.

4. Drilled 1891–92. Altitude of top of casing, 4,753 feet; depth, 888 feet. Oil. Flows a small stream of somewhat alkaline water. Water stands around the casing in a small pool through which gas rises in large amount. No odor.

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[a] Wells 1 to 14 were drilled by the Pennsylvania Oil and Gas Company (see pp. 38–39), but have recently been acquired by the Franco-American Company, which owns also the Ascos wells, described on page 69.

5. Drilled in 1895. Altitude of top of casing, 4,752 feet; depth, 809 feet. Oil.

6. Drilled in 1895. Altitude of top of casing 4,753 feet; depth, 873 feet. Oil.

7. Drilled in 1895. Altitude of top of casing, 4,829 feet; depth, 1,075 feet. Oil.

8. Drilled in 1895. Altitude of top of casing, 4,852 feet; depth, 1.165 feet. Oil.

9. Drilled in 1901 as a test well. Altitude of top of casing, 4,753 feet; depth, 2,350 feet. No oil. Well was cased, and this proved that the water came from the Shannon oil sand. Not a flowing well.

10. Drilled in 1902. Altitude of top of casing, 4,754 feet; depth, 847 feet. Oil.

11. Drilled in 1902. Altitude of top of casing, 4,756 feet; depth, 856 feet. Oil.

12. Drilled in 1902. Altitude of top of casing, 4,757 feet; depth, 843 feet. Oil overflows around casing. Considered the best well of this company.

13. Drilled in 1902. Altitude of top of casing, 4,756 feet; depth, 776 feet. Oil.

14. Record not obtained.

The four wells described below were drilled by the Franco-American Oil Company.

15. Drilled in 1910. Top of Shannon, 724 feet; through Shannon, 757 feet; depth, 779 feet. Three or four barrels a day.

16. Drilled in 1910. Top of Shannon, 664 feet; through Shannon, 689 feet; depth, 710 feet. Fifteen to twenty barrels a day.

17. Drilled in 1910. Depth not obtained. Gas enough to run a boiler and a showing of oil.

18. Record not obtained.

In 1910 a well was drilled by the Franco-American Company in the SW. ¼ SW. ¼ sec. 29, T. 39 N., R. 78 W., to a depth of 1,930 feet. This well struck water at 600 feet and the Shannon sandstone (?) at 645 feet. There was a slight showing of oil and gas near its top.

As already stated (p. 65) the oil in these wells is struck in the lower of the two sands which here represent the Shannon. The wells were drilled about 30 feet into the lower sand.

THE ASCOS WELLS.

The Ascos wells are five in number and are situated just southeast of the wells drilled by the Pennsylvania Oil and Gas Company.

1. Drilled in 1905. Altitude of top of casing, 4,771 feet; oil sand, 826 feet. Slight showing of oil and gas.

2. Drilled in 1905. Altitude of top of casing, 4,764 feet; oil sand, 772 feet; depth of well, 858 feet. Oil; good producer.

3. Drilled in 1905. Altitude of top of casing, 4,762 feet; oil sand, 720 feet; depth of well, 800 feet. Oil; good producer.

4. Drilled in 1905. Altitude of top of casing, 4,760 feet; oil sand, 875 feet. Oil and gas; shows oil and gas 35 pounds pressure; small producer.

5. Drilled in 1905. Oil sand, 730 feet; depth of well, 800 feet. Oil and gas; good producer.

In 1907 a Swedish company drilled one well in the NE. ¼ NE. ¼ sec. 2, T. 40 N., R. 79 W., to a depth of 1,050 feet. The altitude of the top of the casing is 4,783 feet. The well flows alkaline water, but an oily scum appears inside the casing. There is no odor of sulphureted hydrogen.

The structure contours shown near the wells (see map, Pl. VII, in pocket) are based directly on the depths at which the oil-bearing sand of the Shannon lentil was struck in them. From reference to these contours it is plain that the crest of the anticline narrows abruptly at Shannon, the axis lying just east of the group of wells. With the exception of well No. 8, all are on the western limb. Just south of Shannon a flattening of the dip, which is here to the northwest, produces a small structural shelf or terrace on the western side of the anticline, and on this the greater number of the wells are located. At Shannon is the point of a small syncline which opens to the north. Well No. 1, which obtained oil from the Shannon sandstone, is situated in the axis of this syncline near its head. Wells Nos. 3 and 9, which obtained water from the same sand, are northwest of No. 1, in the axis of the syncline, at a point where the Shannon sand is 200 feet lower than in No. 1. The well of the Swedish company and Ascos well 1 are both in another minor syncline lying west of the first. They obtained artesian water, apparently from the Shannon sandstone, whereas Ascos wells 2, 3, 4, and 5, situated a little east of well 1 on the limb of the anticline, obtained oil from the same sand.

It seems evident from the foregoing that the oil in this locality is directly associated with the anticlines and that it is backed by artesian water. The water contains instead of salt (NaCl), its content in many eastern fields, certain "alkalies," among which sodium sulphate is doubtless prominent, although analyses have not been made. Ascos well 1 obtained water at a horizon 75 feet above that at which Shannon well No. 1 obtained oil. The lower limit of the oil zone is probably somewhat irregular, being influenced by the shape and steepness of the anticline at various points.

Gas was obtained in Ascos No. 3 from the Shannon sandstone. This well struck the sand at about the same depth as Ascos No. 5, which is south of it. It seems probable that a very small secondary fold or dome occurs at this point and this allows the accumulation of gas here.

The small shoulder of the anticline occurring in the northern part of sec. 3, T. 40 N., R. 79 W., and the extreme southern portion of sec. 35, T. 41 N., R. 79 W., being similar in many respects to the structure on which the Shannon wells are located, seems to offer favorable conditions for the accumulation of oil. No drilling has yet been done here, however.

The occurrence of the oil seeps in sec. 11, T. 40 N., R. 79 W., shows that oil is present in the Shannon sandstone at this locality and probably somewhat north of it; perhaps all the way to the wells. The seeps themselves are small.

At other points along the strike of the beds northwest or southeast of Shannon no oil seeps and no outcrops of oil-bearing sand were found except that noted in sec. 30, T. 41 N., R. 79 W. (See p. 68.) The accumulation at Shannon seems to be due to the peculiar shape of the anticline at that place, which gives a comparatively large gathering ground on the structural slope below for the oil and at the same time an excellent reservoir at the crest of the anticline for its retention.

On the north and east the limits of the oil pool are not yet determined. A well was drilled on Sherwood Creek, in the middle of sec. 31, T. 41 N., R. 78 W., in 1895, by the Wyoming Lubricating Company. The depth reached, however, was only 1,300 feet, and as the Shannon sandstone is somewhat deeper at this point the well proved nothing as to the presence or absence of oil. It seems probable that oil will not be struck below the 3,600-foot contour, for at that horizon water was encountered in Shannon wells Nos. 3 and 9. On the southeast the oil pool is very probably limited by the faults above mentioned.

WALL CREEK SANDSTONE LENTIL.

OUTCROPS AND THICKNESS.

The Wall Creek sandstone lentil is not brought to the surface on the Salt Creek anticline. It does outcrop, however, on the flank of the Powder River anticline, in a bold escarpment east of Wall Creek, 10 miles west of the Salt Creek field, as shown in Plate VIII, *A*. It is not there important as an oil-bearing stratum, but it outlines the Tisdale dome much as does the Shannon sandstone in the Salt Creek field, and disappears in a syncline on the west, rising again along the flank of the Bighorn Mountains. Along Wall Creek the total thickness of the resistant sandstone capping the escarpment is 80 feet. It is here underlain by 5 feet of shale and below that by soft sandstone with two hard beds of sandstone considerably lower. (See columnar section, Pl. VII.)

In a rather hurried examination of the Wall Creek sandstone in this locality no indications of oil were found. A quotation here from Samuel Aughey's report[a] is of interest:

> Conformably to these [the Benton] shales, but several miles farther eastward, the Fox Hills sandstones appear in lofty escarpments, forming the eastern boundary of Wall Creek. * * * While there is some sandrock of the upper [Fox Hills] series stained and in some places saturated with oil, there is not enough to justify expectation of even small results from that source.

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[a] Rept. Territorial Geologist of Wyoming, 1886, pp. 73-75.

There is little doubt that the reference is here to the Wall Creek sandstone in the escarpment east of Wall Creek. It is now known that this sand is of Colorado and not Fox Hills age. The important part of the quotation is the statement that this sandstone bears oil, though in small amount, in this locality.

OIL SEEPS.

In the Salt Creek field indications of a lower oil-bearing sand than the one reached by the Shannon wells are given by numerous oil seeps occurring within the encircling outcrop of the Shannon sandstone. Important among these is the Iba spring, already described (p. 38), which occurs in the SW. ¼ sec. 13, T. 40 N., R. 79 W., in the bed of Salt Creek.

Another seep in the bed of Salt Creek occurs in the SW. ¼ NW. ¼ sec. 25, T. 40 N., R. 79 W., just north of the mouth of a draw which comes in from the southwest. Bubbles of gas may be seen rising at intervals through the water and spreading an oily film on the surface.

On Castle Creek, a little above its junction with Salt Creek in the SW. ¼ sec. 25, T. 40 N., R. 79 W., sand and gravel along the stream bed is saturated with oil which may rise from below. It is not a definite oil-bearing stratum.

It is reported that the Dutch No. 1 well was located beside a large oil seep that is now concealed by the oil reservoir south of the well.

As the Shannon sandstone has been removed from the part of the dome in which these oil seeps occur it is evident that the oil which finds its way to the surface at these seeps must be derived from some other source. W. C. Knight, of the University of Wyoming, wrote in 1896:[a]

> Judging from the data at hand there are two oil horizons at Salt Creek. The upper one is the one from which the oil is obtained at the present time, and the lower sand will be found about 1,000 feet below.

Professor Knight thus realized the existence of a lower oil sand, but considerably underestimated the distance between the two oil sands.

WELLS THAT OBTAIN OIL FROM THE WALL CREEK SAND.

DUTCH WELL NO. 1.

As already stated (p. 39), Dr. Porro examined the field in 1906 for the Holland company,[b] called the Petroleum Maatschappij Salt Creek, and, it is said, located the "gusher" well (Dutch No. 1) near a large oil seep in the NE. ¼ SE. ¼ sec. 23, T. 40 N., R. 79 W., about

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[a] Petroleum of Salt Creek, Wyoming: Bull. Univ. Wyoming.

[b] The Holland company is always spoken of as the Dutch Company and the name is therefore adopted in this report.

3 miles south of the Shannon wells. The well was drilled in the fall of 1908 by J. E. Stock and his father. Shale was encountered for over 1,000 feet. The oil sand was struck October 21, and oil and gas in small quantities were found near its top. The drilling was continued that night, and at 11 o'clock p. m. the gas took fire from the light of the lantern. The driller was badly burned, and no work was done the following day, but on October 23 drilling was continued to a depth of 24 feet into the sand. Oil rose to the top of the casing and then above it higher and higher until the column shot 100 feet into the air. The well was cased for the first 550 feet with 10-inch casing. Then 8¼-inch casing was put down inside the 10-inch and extended to the bottom of the well. The 8¼-inch casing was capped, but the force of the accumulated gas twice blew off the cap. The third attempt to cap the well was successful. It is reported that the total depth of the well is 1,076 feet.

At present the oil finds its way to the surface on the outside of the casing, as the well is still capped. About once a day the oil rises within a foot or two of the surface, where it may be seen, greatly agitated by the gas which rises through it. Suddenly it surges upward some 6 or 8 feet above the surface in a great fountain, throwing out many barrels of oil, which flow down into a reservoir formed by building an earthen dam across a gulch on the edge of which the well is located. A valve at the top of the casing when opened emits gas and then gas and oil under heavy pressure with a roar like a steam whistle.

The periodic flow of such a well is probably caused by much the same forces as those operative in geysers. In a geyser water and steam accumulates; in an oil well, oil and gas. The well is filled with a column of oil. Gas accumulates at the bottom. The weight of the long column of oil above holds the gas under great pressure. The gas accumulates until its power of expansion is sufficient to overcome the weight upon it, when it suddenly expands, forcing the oil out from the mouth of the well and itself escaping. The well thus cleared of gas is quiescent until the casing fills with oil and sufficient gas accumulates at the bottom again to force out the oil. (See Pl. X, *B*.)

IBA WELL.

The Iba well, located in the NE. ¼ SE. ¼ sec. 22, T. 40 N., R. 79 W., on Bothwell Draw, was drilled by Stock for the Holland company. It is reported that a light oil was struck in shale at a depth of 63 feet. The well is said to have been continued through shale to a depth of 1,263 feet, but no other deposit of oil was encountered. It would probably produce from 8 to 10 barrels a day. At present a large wooden plug is set in the top of the casing. On removing this the oil is seen within 2 feet of the top. Bubbles of gas rise through it continually. It appears not unlikely that the oil in this well is derived from a "pocket" in the shale, the oil of which has worked its way upward from the Wall Creek sandstone below. A reference to the table of analyses will show that the oils from this well and the Dutch well No. 1 are very similar.

OTHER WELLS OF THE DUTCH COMPANY.

The wells listed below were also sunk by the Dutch Company:

2. Drilled in 1910. NE. ¼ NE. ¼ sec. 26, T. 40 N., R. 79 W. Elevation of top of casing, 4,867 feet; depth to Wall Creek sandstone, 1,050 feet. Oil; good producer, equal to or better than No. 1.
3. Drilled in 1910. SW. ¼ sec. 24, T. 40 N., R. 79 W. Elevation of top of casing, 4,831 feet; depth to Wall Creek sandstone, 990 feet. Oil; best showing of oil near top of sand. Good producer; flows two or three times a day.
4. Drilled in 1910. Middle of sec. 26, T. 40 N., R. 79 W. Elevation of top of casing, 4,927 feet; top of Wall Creek sandstone, 1,000 feet. Almost constant flow of oil estimated by the drillers to be between 500 and 600 barrels a day.

The same company has put down 14 shallow wells which obtained oil in shale in limited quantity in secs. 22, 23, 24, 25, 26, and 27, T. 40 N., R. 79 W.

WELL OF THE STOCK OIL COMPANY.

A well of the Stock Oil Company is located in the SW. ¼ NE. ¼ sec. 25, T. 40 N., R. 79 W. It was drilled by J. E. Stock and his father after they had completed work on the Dutch well No. 1. Oil is said to have been struck in shale at a depth of 313 feet. The well was continued to a depth of 1,050 feet, but the oil sand was not encountered, as it probably lies at still greater depth at this point. The well is said to produce by pumping 12 to 14 barrels in twenty-four hours. Analysis of a sample of the oil from this well (see table on p. 80) shows that although it is similar in many respects to that obtained from the Dutch well No. 1 it contains much less naphtha. This small content of naphtha may or may not be due to the fact that the oil had been standing in the casing for some months, undisturbed.

WELLS OF THE CALIFORNIA OIL COMPANY.

The wells described below were drilled by the California Oil Company in 1909 and 1910.

1. Drilled in 1909. Close to the old Stock well. Sand, 1,166 feet; oil, 1,180 feet; depth, 1,238 feet. About 65 barrels a day; flows once or twice a day.
2. Drilled in 1910. West center of sec 6, T. 39 N., R. 78 W. Depth, 680 feet. Oil and gas in shale; about 18 barrels a day by bailing.

3. Drilled in 1910. East side of sec. 11, T. 39 N., R. 79 W. Struck oil in shale, 1,176 feet. Large producer; when struck, threw oil above the derrick and flowed from the pipe for more than three hours.

4. Drilled in 1910. SE. ¼ sec. 36, T. 40 N., R. 79 W. Wall Creek sand, 1,287 feet. Brackish water at 27 feet in sand; depth, 1,447 feet; still in sand; at 110 feet in sand got a small showing of oil.

5. Drilled in 1910. Sec. 7, T. 39 N., R. 78 W. Struck oil in shale at 700 feet.

6. Drilled in 1910. South of center of sec. 30, T. 40 N., R. 78 W. Shut down at 1,700 feet without reaching sand.

7. Drilled in 1910. Sec. 25, T. 40 N., R. 79 W., south of No. 1. Wall Creek sand, 1,151 feet; oil, 1,170 feet; depth, 1,205 feet. About 65 barrels a day.

8. Drilled in 1910. North side of sec. 1, T. 39 N., R. 79 W. Wall Creek sand, 1,278 feet; depth, 1,310 feet. Brackish water and slight showing of oil.

Perhaps the most interesting of the wells drilled by the California company is No. 3, above, which struck oil under pressure in shale. The amount of oil which is said to have flowed from the well when it was struck seems unusually large for a shale well. Oil travels much more slowly through shale than through sandstone, and where large quantities are produced from shale a slight crevice or fissure is generally present. This fissure may be a fraction of an inch in width and yet be of sufficient extent to contain large quantities of oil and to allow the oil to reach the well rapidly. This is the only adequate explanation of the extraordinary flow of this well, but there is nothing to be observed at the surface to prove or disprove its applicability, for the rocks near the well are concealed by surface wash in a broad valley. The well does not reach within 400 feet of the Wall Creek sandstone below. It is significant that numerous wells throughout the field have encountered oil in shale, many of them showing signs of gas, which bubbles up continually through the column of oil. No other wells, however, have flowed as this one did. This well probably does not differ in kind from such wells as the Iba well, on Bothwell Draw.

DAKOTA (?) SANDSTONE.

The Dakota sandstone, which carries oil at the Powder River anticline, probably underlies the Salt Creek anticline as well. Whether or not it is here oil bearing it is impossible to say, as the Dakota in this region is variable in character, at some places consisting of fine-grained sandstone and shale, and at others, as in the Powder River anticline, of coarse conglomeratic sandstone. Its oil content is likely to vary with its lithologic character. The structural conditions in the Salt Creek field are, however, very favorable to the accumulation of oil in this stratum, and the great thickness of the shale above it would tend to prevent its escape.

At Dutch well No. 1 the Dakota sandstone is estimated to be about 2,250 feet below the surface. At the crest of the Teapot dome it is about 3,200 feet below the surface. Such depths are not too great for drilling in the rather soft shale of this region.

For the character of the Dakota oil see page 78; also the table of analyses on pages 80–82.

RELATION OF OIL TO THE ANTICLINE.

In general, where, as in the Salt Creek field, oil occurs at or near the crest of an anticline the presumption is that it is backed by water. Were this not the case, the oil would settle by its own weight down the structural slope into the syncline. Where the oil occurs on an anticline the porous rock which forms the reservoir for the oil may be considered as saturated with water, oil, and gas. The oil being lighter than the water is forced above it, the gas is probably dissolved in the oil under great pressure. Under these conditions if a well taps the sandstone below the oil horizon it obtains water, and if it taps it at the oil horizon it obtains oil. Should much gas be dissolved under pressure in the oil, and should the sandstone be tapped at the top of the oil horizon, the gas, suddenly relieved from pressure, separates from the oil and a gas well is the result. It seems improbable that the great pressures which occur in wells like Dutch No. 1 of the Salt Creek field are due to water under artesian pressure which backs the oil. The water doubtless has its effect, but the direct cause which produces " flowing wells " is the accumulation of gas.

In regard to the location of oil wells about a dome, several points should be considered. Important among these is the gathering ground for the oil. The oil which is obtained from a porous sandstone by drilling at a certain point was, it is believed, originally distributed in small amounts through that sandstone or the adjacent rocks. For a long time it has been working its way upward through the pores of the sandstone, impelled, perhaps, by the pressure of the water below it or by other agencies. It has collected in quantity in certain parts of the sandstone which are capable of retaining it, but the quantity collected depends on the area which has supplied the oil. In the Salt Creek dome, for example, the eastern slope extends for many miles and its dips of from 5° to 10° are amply sufficient to cause the oil to rise if it is backed by artesian water. Wells located on the eastern side of the dome may tap oil reservoirs which have thus been supplied from this broad area. On the western side of the dome, however, the dip of the rocks is comparatively steep. The slope is abrupt and short, and the axis of the syncline lies only a mile west of the crest of the dome. Oil occurring in the sandstone west of the synclinal axis would migrate westward, away from the Salt

Creek dome. Wells located on the western side of the dome would therefore obtain oil collected from a slope a mile long, instead of one several miles long, as on the eastern side of the dome. As to the extent of the oil pool on the east, it is significant that California No. 8, near the road on the north side of sec. 1, T. 39 N., R. 79 W., reached the sand and obtained brackish water and a small showing of oil. This well is a little outside the 5,600 contour shown on the map. Wells Nos. 1 and 7 of the same company, 1½ miles north of well No. 8, are inside this contour and obtained a good flow of oil. If the oil is distributed regularly according to the elevation of the sand above sea level the area outside the 5,600 contour probably does not bear oil in paying quantity. If, however, minor folds occur in this area, which do not reach the surface or which have not been observed, they may retain oil along their axes in sufficient quantity to warrant development.[a]

In some eastern fields a structural "terrace," formed by the abrupt flattening of a slope, with steeper dips above and below, is propitious to the accumulation of oil. As already noted (p. 70) a small "terrace" of this kind occurs southwest of Shannon, and on it most of the Shannon wells are located.

Faults in the Salt Creek dome may break the continuity of the oil sand and interfere with the distribution of the oil. Unfortunately, they are difficult to detect in the soft shale on the higher portions of the dome. The Wall Creek sandstone is probably about 150 feet thick in this area, and a fault of that amount might completely break the stratum and seal the ends with a comparatively impervious shale. Such a sealed break might furnish conditions for the accumulation of oil in the sandstone on the lower side of the fault, but might render the sandstone above barren of oil.

No drilling has yet been done in the Teapot dome, but the structural conditions here are very favorable for the accumulation of oil. There is a broad gathering ground to supply the oil, sufficient dip to cause it to accumulate, and but few faults to break the continuity of the oil sands. Both the Shannon and Wall Creek sandstones underlie this dome, the Shannon at a depth of 100 or 200 feet below the surface, the Wall Creek at a depth somewhat more than 2,000 feet. Either one of the two minor crests which form the Teapot dome should furnish good locations for prospecting. It is noteworthy that no oil seeps occur in this part of the field except the one reported by T. S. Harrison (p. 67). This fact is somewhat against the occurrence of oil in this dome, for in the Salt Creek dome oil seeps are fairly numerous where oil has been found. This, however, is but negative evidence.

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[a] A well recently drilled by the Franco-American Company in the SW. ¼ SW. ¼ sec. 18, T. 40 N., R. 78 W., is reported to produce 25 barrels a day. A second well drilled by the same company in the SW. ¼ SW. ¼ sec. 19, T. 40 N., R. 78 W., obtained about 17 barrels of oil in shale. When the Wall Creek sandstone was encountered the well was shot and a small flow of oil was obtained. Both wells are considerably outside of the 5,600-foot contour.

ORIGIN OF THE OIL.

In regard to the origin of the oil of this general region little can be said. It is at present found for the most part in sandstone, but whether it originated there or in the adjacent shale and later found its way into the sandstone and whether it is of animal or of vegetable origin are open questions. The oil occurs at three widely separated horizons—the Dakota, a conglomeratic sandstone, contains a heavy oil of 0.916 specific gravity; the Wall Creek sandstone, 1,350 feet above the Dakota sandstone, carries a light oil of 0.822 gravity; the Shannon sandstone, 1,970 feet above the Wall Creek, carries a heavy oil of 0.909 gravity. The Dakota oil has an asphaltum base and contains sulphur.[a] The oils of the Wall Creek and Shannon sandstones are paraffin oils, practically free from asphaltum and sulphur. The Dakota sandstone carries occasional leaves but is otherwise nonfossiliferous. The Wall Creek and Shannon sandstones contain the remains of sea weeds and marine invertebrates. The rocks intervening between the three oil-bearing sandstones are for the most part shale. In the Mowry shale member, 300 feet above the Dakota sandstone, there are great numbers of fish scales, and in a thin sandstone lens 1,300 feet above the Wall Creek sandstone lentil there are great numbers of fish teeth. Fishes were evidently plentiful in the ocean in which the shale was deposited, and their bodies may have contributed to the oil supply. The presence of sulphur in oil has usually been taken to denote animal origin. The Salt Creek oil is notably low in sulphur.

The oil in the Pierre shale is practically the same as that which occurs in the Wall Creek sandstone of the underlying Benton shale. Whether or not the oil in the shale is derived from that in the sandstone, rising from it along small fissures in the shale, is a subject for discussion. Such a hypothesis appears to explain the facts in the field. If the oil is native to the shale and has in part passed downward into the Wall Creek sandstone it must have done so against the force of the artesian water in the sand. With our present knowledge it is impossible to tell. Whatever may have been the origin of the oil the principal flow is in general to be expected from the sandstone, but oil in quantity may be occasionally struck in shale, as at California No. 3. The water which backs the oil in the Wall Creek sandstone is slightly brackish but could scarcely be termed salt. That associated with the Shannon oil carries considerable quantities of the alkalies. As noted in the descriptions of the wells, the water from Shannon well No. 3 and Ascos well 1 gives off the odor of sulphureted hydrogen. This water probably comes from the oil-bearing Shannon sandstone. In the NW. ¼ sec. 30, T. 41, N., R. 79 W., a sulphur spring, already described (p. 68), emerges from the Shannon sandstone. Sulphur water is also associated with the oil in the Powder River field.

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[a] Knight, W. C., and Slosson, E. E., The Dutton, Rattlesnake, Arago, Oil Mountains, and Powder River oil fields; Bull. Univ. Wyoming School of Mines, Petroleum series No. 4.

ANALYSES OF THE OIL.

The following analyses of the Salt Creek oils were made in the laboratory of the United States Geological Survey under the direction of Dr. David T. Day. The table includes also determinations of the specific gravity and flashing point of oil from the Tisdale (or Powder River) field, as published by Knight and Slosson and by Sir Boverton Redwood. Analyses of well-known oils from West Virginia, Illinois, and Oklahoma, made by the United States Geological Survey, are also given for comparison.

Dr. Day speaks as follows of the Salt Creek oils:

> These analyses show that the oils are of two general classes. One (Shannon Nos. 10 and 12) is suitable for lubricating purposes; the others are suitable for profitable refining for the gasoline and kerosene which they will yield, together with lubricating oils, paraffin, etc. The specific gravity of the distillate, the absence of asphalt, and the comparatively low proportion of unsaturated hydrocarbons unite to show that these oils have a paraffin base, and the quantity of paraffin obtained from most of them is as great as is usually expected. No determination of water or sulphur was made, the distillate showing practically the absence of both of these substances.

Analyses of oils from Salt Creek, Wyoming.

[Made in the laboratory of the United States Geological Survey, David T. Day, in charge.]

Wells.	Depth of wells.	Physical properties.			Distillation by Engler's method.								Paraffin.	Unsaturated hydrocarbons.	
		Gravity at 60° F.		Color by reflected light.	Begins to boil.	By volume.									
		Specific.	Baumé.			To 150° C. (naphtha, gasoline, benzine).		150-300° C. (water-white oil).		Residuum (lubricating oil, paraffin, and tar).		Total.		Crude.	150-300° C.
						Cubic centimeters.	Specific gravity.	Cubic centimeters.	Specific gravity.	Cubic centimeters.	Specific gravity.	Cubic centimeters.			
	Feet.				°C.								*P. ct.*	*P. ct*	*P. ct.*
Dutch No. 1 (sample 1)	1,000+	0.8221	40.3	Green	76	8.0	0.7220	38.0	0.7881	49.3	0.8963	95.3	4.97	16.4	4.0
Dutch No. 1 (sample 2)		.8255	39.6	do	76	11.0	.7210	36.0	.7934	50.0	.9068	97.0	4.91	13.2	4.0
Dutch No. 1 (sample 3)		.8221	40.3	do	66	16.0	.7114	29.0	.7911	52.4	.8861	97.4	6.44	14.4	5.0
Shannon No. 10	847	.9097	23.9	Olive green	204			12.5	.7673	86.9	.9192	99.4	1.14	15.2	6.0
Shannon No. 12	843	.9085	24.1	Green	213			10.0	.8673	86.6	.9211	96.6		14.8	8.0
Iba		.8314	38.4	do	84	11.0	.7215	34.0	.7875	54.0	.8923	99.0	5.56	13.2	4.0
Stock		.8563	33.5	Dark green	126	1.0		36.0	.7854	62.4	.9032	99.4	5.63	13.2	4.0

Analyses of well-known oils from other fields given here for comparison with Salt Creek oils.

[Made in the laboratory of the United States Geological Survey, David T. Day, in charge.]

Wells.	Depth of wells.	Physical properties.			Distillation by Engler's method.								Paraffin.	Asphalt.	Unsaturated hydrocarbons.		Sulphur.
		Gravity at 60° F.		Color by reflected light.	Begins to boil.	By volume.											
						To 150° C. (naphtha, gasoline, benzine).		150–300° C. (water-white oil).		Residuum (lubricating oil, paraffin, and tar).		Total.			Crude.	150–300° C.	
		Specific.	Baumé.			Cubic centimeters.	Specific gravity.	Cubic centimeters.	Specific gravity.	Cubic centimeters.	Specific gravity.	Cubic centimeters.					
	Feet.				*°C.*								*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
McFarlan pool, Cairo salt sand. Cairo Oil Co., Cairo, W. Va.	1,494	0.8005	44.9	....	90	16.0	0.7175	39.0	0.7773	45.0	0.8618	100.0	4.22	......	8.4	2.0	......
Volcano pool, heavy oil sand, Volcanic Oil and Gas Co., Parkersburg, W. Va.	350	.8750	30.0	....	186	......	......	17.0	.8314	83.7	.8822	100.7	......	......	21.6	5.0	......
Robinson pool, Crawford Co., Ill.	950	.846	35.5	Medium green.	80	8.0	.7183	39.0	.7941	53.0	......	100.0	......	......	......	......	0.16
Duncansville pool, Montgomery Township, Crawford County, Ill.	970	.915	23.0	Brown.	80	1.0	......	24.5	.8391	74.5	......	100.0	......	......	......	......	.39
Glenn pool, Oklahoma, sec. 7, T. 17 N., R. 12 W.	1,500	.8459	35.5	Black.	105	8.5	.7566	42.0	.8001	49.9	.9032	100.4	6.98	.45	22.8	7.0	......

Analyses published by Knight and Slosson.[a]

	Specific gravity.	Flashing point.	Color.	Sulphur.
Salt Creek (Shannon oil)	0.910	105	Green.	....
Powder River (Tisdale) field				
Oil Canyon (open well or pit)	.916	118	....	0.31
Trail Canyon	.913	80	....	.10
Box Canyon in Salt Canyon	.933	134	....	.67

[a] Knight, W. C., and Slosson, E. E., Petroleum of Salt Creek, Wyoming: Bull. Univ. Wyoming School of Mines, Petroleum series No. 1. The Dutton, Rattlesnake, Arago, Oil Mountain, and Powder River Oil fields: Bull. Univ. Wyoming School of Mines, Petroleum series No. 4.

Analyses published by Redwood.[a]

	Specific gravity.	Flashing point.
		°C.
Salt Creek (Shannon) No. 1	0.909	64
Salt Creek (Shannon) No. 7	.905	52
Tisdale's ranch	.916	93

[a] Redwood, Boverton: Petroleum and its products, vol. 1, 2d ed.

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 453

RESULTS OF SPIRIT LEVELING IN MINNESOTA

1897 TO 1910, INCLUSIVE

R. B. MARSHALL, CHIEF GEOGRAPHER

WORK DONE IN COOPERATION WITH THE STATE OF MINNESOTA
DURING 1909 AND 1910

WASHINGTON
GOVERNMENT PRINTING OFFICE
1911

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RESULTS OF SPIRIT LEVELING IN MINNESOTA, 1897 TO 1910, INCLUSIVE.

R. B. MARSHALL, *Chief Geographer.*

INTRODUCTION.

Scope of the work.—All results of spirit leveling in Minnesota previously published by the United States Geological Survey and all the results of later work in the State are included in this report, rearranged by quadrangles. All elevations are based on the precise-level net adjustment of 1907 by the United States Coast and Geodetic Survey to a common mean sea level datum. The part of this net which lies within or along the borders of Minnesota comprises the line along Mississippi River from the southeast corner of the State to Lake Itasca, the line from Brainerd via Aitkin and Grand Rapids to Cass Lake, the line of the Corps of Engineers, United States Army from St. Paul to Duluth, and also the following lines by the Coast and Geodetic Survey: St. Cloud via Evansville and Childs to Ortonville, and Evansville via Fergus Falls and Crookston to Stephen.

Personnel.—The field work previous to 1903 was done under the general direction of J. H. Renshawe, geographer; that for 1903 to 1906, inclusive, under H. M. Wilson, geographer; and the later work under W. H. Herron, geographer, under the general direction of R. B. Marshall, chief geographer. Credit is given to the different levelmen in the introduction to each list. The office work of computation, adjustment, and preparation of lists was done mainly by S. S. Gannett, geographer, and D. H. Baldwin, topographer, and since 1907, under the general direction of E. M. Douglas, geographer.

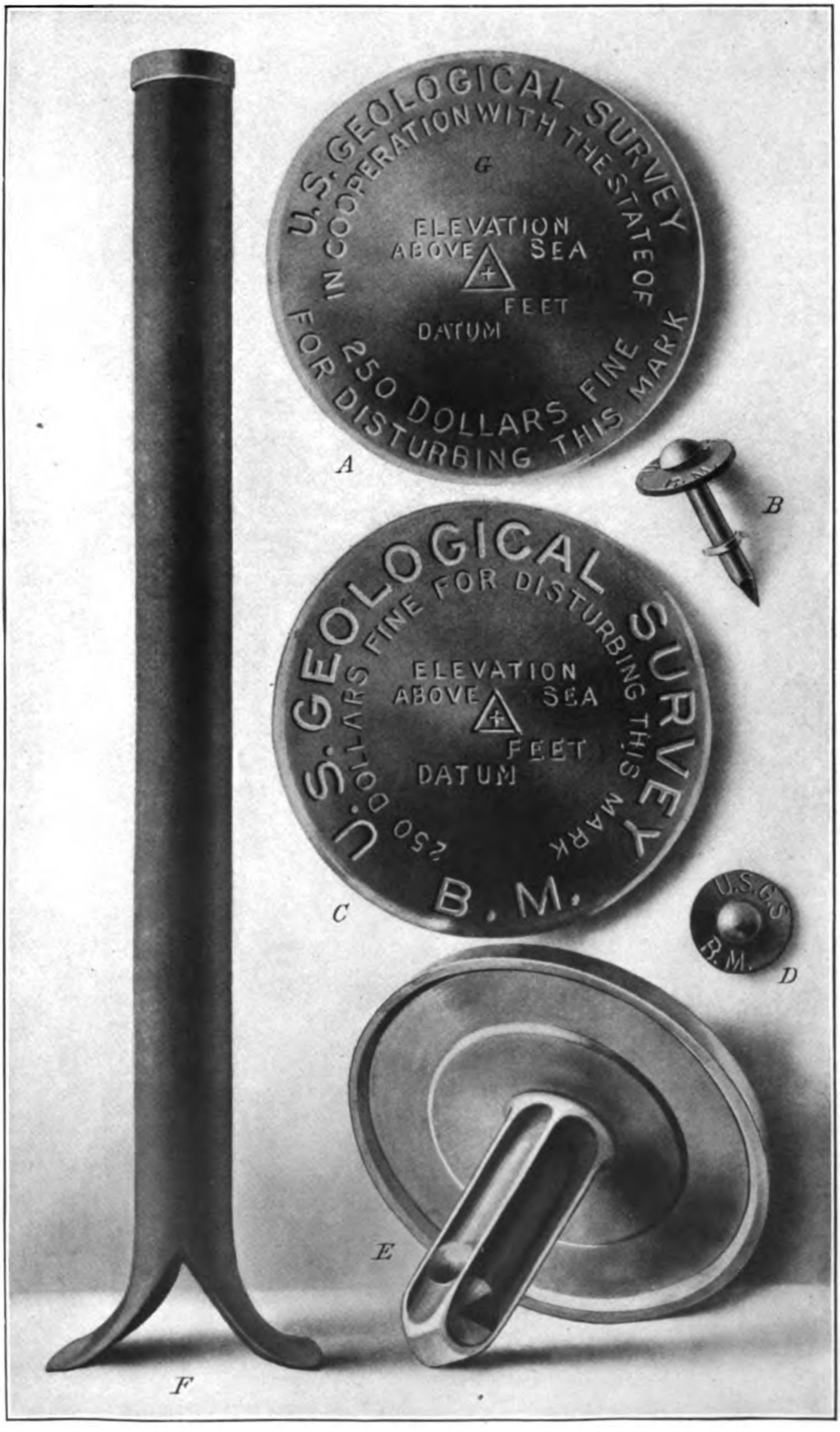
Classification.—The elevations are classified as precise or primary, according to the methods employed in their determination. For precise-level lines instruments and rods of the highest grade are used, each line is run in both forward and backward directions, and every precaution is taken to guard against error. The allowable divergence between the forward and the backward lines in feet is represented by the formula $0.017\sqrt{D}$, in which D is the distance in miles between bench marks. For primary lines standard Y levels are used; lines are run in circuits or are closed on precise lines, with an allowable closing error in feet represented by 0.05 $\sqrt{D}$, in which D is the length of the circuit in miles, sufficient care being given to the work to maintain this standard. For levels of both classes careful office adjustments are made, the small outstanding errors being distributed over the lines.

Bench marks.—The standard bench marks are of two forms. The first form is a circular bronze or aluminum tablet (*C* and *E*, Pl. I), 3½ inches in diameter and one-fourth inch thick, having a 3-inch stem, which is cemented in a drill hole in solid rock in the wall of some public building, a bridge abutment, or other substantial masonry structure. The second form (*F*, Pl. I), used where masonry or rock is not available, consists of a hollow wrought-iron post 3½ inches in outer diameter and 4 feet in length after being split at the bottom and expanded to a width of 10 inches in order to give a firm bearing on the earth. A bronze or aluminum-bronze cap is riveted over the top of the post, which is set about 3 feet in the ground. A third style of bench mark with abbreviated lettering (*B* and *D*, Pl. I), is used for unimportant points. This consists of a special copper nail, 1½ inches in length, driven through a copper washer seven-eighths of an inch in diameter.

The tablets as well as the caps on the iron posts are appropriately lettered, and for cooperating States the fact of such cooperation is indicated by the addition of the State name (at *G*, Pl. I).

The numbers stamped on the bench marks described in the following pages represent the elevations to the nearest foot, as determined by the levelman. These numbers are stamped with $\frac{3}{16}$-inch steel dies on the tablets or post caps, to the left of the word "feet." The office adjustment of the notes and the reduction to mean sea level datum may so change some of the figures that the original markings are 1 or 2 feet in error. It is assumed that engineers and others who have occasion to use the bench-mark elevations will apply to the Director of the United States Geological Survey at Washington, D. C., for the adjusted values, and will use the markings as identification numbers only.

Datum.—All United States Geological Survey elevations are referred to mean sea level, which is the level that the sea would assume if the influence of tides and winds were eliminated. This level is not the elevation determined from the mean of the highest and the lowest tides, nor is it the half sum of the mean of all the high tides and the mean of all the low tides, which is called the half-tide level. *Mean sea level is the average height of the water, all stages of the tide being considered.* It is determined from observations made by means of tidal gages placed at stations where local conditions, such as long narrow bays, rivers, and like features will not affect the



GEOLOGICAL SURVEY BENCH MARKS.

A, Tablet used in cooperating States. The State name is inserted at *G*.
B and *D*, Copper temporary bench mark, consisting of a nail and copper washer.
A, *C*, and *E*, Tablets for stone or concrete structures.
F, Iron post used where there is no rock.

height of the water. To obtain even approximately correct results these observations must extend over at least one lunar month, and if accuracy is desired they must extend over several years. At ocean stations the half-tide level and the mean sea level usually differ but little. It is assumed that there is no difference between the mean sea level as determined from observations in the Atlantic Ocean, the Gulf of Mexico, or the Pacific Ocean.

The connection with tidal stations for bench marks in certain areas that lie at some distance from the seacoast is still uncertain, and this fact is indicated by the addition of a letter or word to the right of the word "Datum" on tablets or posts. For such areas corrections of published results will be made from time to time as the precise-level lines of the United States Geological Survey or other Government organizations are extended.

There are included herewith the results of leveling in certain wet, overflowed, or swampy lands, ceded by the Chippewa Indians, in the counties of Beltrami, Itasca, Marshall, Polk, Red Lake, and Roseau, the survey of which was specifically provided for by Congress June 21, 1906, and finally reported upon in House Document 27, Sixty-first Congress, first session. The elevations of bench marks given in that document have been corrected to agree with the adjustment of precise leveling made in 1907.

Maps of the following quadrangles, wholly or partly in Minnesota, have been published by the United States Geological Survey up to February 15, 1911. They may be obtained for 5 cents each, or $3 a hundred, on application to the Director of the Survey at Washington, D. C.

Anoka.
Duluth.
Fargo (N. Dak.-Minn.).
Herman.
Minneapolis.
Minnetonka.
Rockford.
St. Croix Dalles (Wis.-Minn.).
St. Paul.
Wahpeton (N. Dak.-Minn.).
White Bear.

PRECISE LEVELING.

Badger, Baudette, Clementson, Crookston, International Falls, Pelland, Red Lake Falls, Roseau, Thief River Falls, and Warroad Quadrangles.

BELTRAMI, ITASCA, MARSHALL, POLK, RED LAKE, AND ROSEAU COUNTIES.

The elevations in the following list are the result of a line of precise levels run by C. H. Semper in 1906 from Crookston to Middle River, and extended in 1907 by E. L. McNair from Middle River northward along the Great Northern Railway to Greenbush; thence along highways via Badger and Roseau to Warroad, a small town on the Canadian Northern Railway at the southwestern extremity of the Lake of the Woods and only about 7 miles south of the forty-ninth parallel; thence eastward along the Canadian Northern Railway to

Baudette, on Rainy River; thence along the south bank of Rainy River—the line being cut through the forest a considerable part of the distance—to International Falls, opposite the older Canadian town of Fort Francis. Elevations are based on the bench mark "City" of the Coast and Geodetic Survey at Crookston, which is taken as 869.278 feet above mean sea level.

CROOKSTON QUADRANGLE.

Crookston along Great Northern Railway via Tilden Junction and Thief River Falls to Middle River (portion of line).

	Feet.
Crookston, Polk County, Minn., "City" bench mark, at entrance of Merchants' National Bank building, on northwest corner of Second and Main Streets; as quare outline on the north side of the top of the first step (Coast and Geodetic Survey bench mark)	869.278
Crookston, 3.38 miles east of, at railroad crossing, southeast corner of fence; iron post stamped "888"	888.509
Crookston, 6.27 miles east of, south side of track, railroad crossing, corner fence; iron post stamped "905"	905.660

RED LAKE FALLS QUADRANGLE.

Crookston along Great Northern Railway via Tilden Junction and Thief River Falls to Middle River (portion of line).

Burwell, 1.82 miles east of, 50 feet south of track, 60 feet west of road, in corner of fence; iron post stamped "927"	927.394
Burwell, 4.63 miles east of, north side of track, 8 feet east of milepost 11; iron post stamped "991"	991.208
Burwell, 7.31 miles east of, 60 feet north of railroad on crossing, 50 feet west of road; iron post stamped "1035"	1,035.800
Burwell, 10.43 miles east of, south side of track, second telegraph pole west of milepost 17; iron post stamped "1103"	1,103.102
Tilden Junction, 2.02 miles north of, east side of track, opposite milepost 59, at fence line; iron post stamped "1095"	1,095.072
Delorme, 0.57 mile north of, railroad crossing, 30 feet west of track, 3 feet north of crossing signboard, 389 feet south of milepost 63; iron post stamped "1092"	1,092.360
Perault, 0.34 mile north of, railroad crossing, east side of track, 358 feet south of milepost 65; iron post stamped "1043"	1,043.307
Perault, 3.13 miles north of, west side of track, 30 feet north of switch to Red Lake Falls, on east margin of highway; iron post stamped "1035"	1,035.459
Red Lake Falls, 1.07 miles north of, between main line track and switch to Red Lake Falls Milling Co., 25 feet east of main track, Great Northern Ry.; iron post stamped "984"	984.674
Red Lake Falls, 4.31 miles north of, west side of track, 8 feet northwest of milepost 5; iron post stamped "1071"	1,071.491
Red Lake Falls, 7.26 miles north of, east side of track, 150 feet east of milepost 2; iron post stamped "1086"	1,086.041

THIEF RIVER FALLS QUADRANGLE.

Crookston along Great Northern Railway via Tilden Junction and Thief River Falls to Middle River (portion of line).

St. Hilaire, 362 feet north of station, road crossing, 30 feet west of track; iron post stamped "1091"	1,091.154
St. Hilaire, 2.59 miles north of, railroad crossing, west of track, at northwest corner of fence; iron post stamped "1102"	1,102.630

	Feet.
St. Hilaire, 5.63 miles north of, railroad crossing, northeast corner of highway, at fence corner; iron post stamped "1124"	1,124.126
Thief River Falls, First National Bank building, west fence, between window; aluminum tablet stamped "1137"	1,137.699
Thief River Falls, 3.58 miles north of, road crossing, 100 feet east of track at southwest corner of fence; iron post stamped "1133"	1,132.963
Thief River Falls, 6.38 miles north of, west side of track, 3 feet north of milepost 35; iron post stamped "1139"	1,139.108
Steiner, 2.46 miles north of, west side of track, 5 feet north of milepost 38; iron post stamped "1152"	1,152.791
Sandridge, 287 feet north of station, west side of track, 30 feet south of water tank; iron post stamped "1157"	1,156.887
Sandridge, 3.02 miles north of, west side of track, 15 feet west of milepost 44; iron post stamped "1144"	1,144.627
Sandridge, 5.95 miles north of, northwest side of track, 20 feet northwest of milepost 47; iron post stamped "1143"	1,143.772
Middle River, 0.75 mile south of, 6 feet west of milepost 50; iron post stamped "1147"	1,147.699

Middle River along Great Northern Railway to Greenbush (portion of line).

Middle River, 2.1 miles north of, 200 feet north of milepost 63, 60 feet east of track; iron post stamped "1169"	1,169.131

BADGER QUADRANGLE.

Middle River along Great Northern Railway to Greenbush (portion of line).

Strathcona, 1.2 miles south of, 360 feet north of milepost 58, 45 feet east of track, at edge of right of way; iron post stamped "1139"	1,139.372
Strathcona, 96 feet west of center of track, 18 feet north of center of wagon road, 9 feet west of ditch; iron post stamped "1126"	1,126.659
Strathcona, 0.75 mile north of, 50 feet west of center of track, 35 feet northwest of milepost 60, at edge of right of way; iron post stamped "1120"	1,120.011
Strathcona, 3.8 miles north of, opposite milepost 63, 45 feet east of track, at edge of right of way; iron post stamped "1099"	1,099.388
Greenbush, 3.6 miles south of, opposite milepost 66, 45 feet west of track; iron post stamped "1071"	1,071.416
Greenbush, 0.5 mile south of, 45 feet west of track, 15 feet northwest of second telegraph pole north of milepost 69; iron post stamped "1073"	1,073.126

Greenbush along highway via Badger, Roseau, and Pequis to Warroad (portion of line).

Greenbush, 1.2 miles north of, on main highway, 30 feet east of road, 45 feet west of railroad grade, 6 feet north of telephone pole; iron post stamped "1075"	1,075.624
Greenbush, 3.6 miles northeast of, 90 feet northeast of schoolhouse, T. 161, R. 42, about at corner of secs. 29, 30, 31, and 32, 20 feet west of road; iron post stamped "1080"	1,080.265
Greenbush, 6.4 miles northeast of, 4 feet north of telephone pole, 21 feet west of road, by third pole north of house; iron post stamped "1086"	1,085.956
Badger Creek; water surface, June 27, 1907	1,066.0
Badger, 375 feet northwest of church, 186 feet northeast of Badger Feed and Sale Stable, 6 feet east of sidewalk, at corner of fence; iron post stamped "1084"	1,084.200

ROSEAU QUADRANGLE.

Greenbush along highway via Badger, Roseau, and Pequis to Warroad (portion of line).

	Feet.
Badger, 3.2 miles northeast of, 42 feet north of fence corner, 12 feet east of center of main road, 170 feet north of house owned by Mr. Anderson, in NE. ¼ sec. 32; iron post stamped "1086"	1,086.282
Fox, 20 feet west of north-south section line, between secs. 26 and 27, 135 feet south of corner of secs. 22, 23, 26, and 27, T. 162, R. 41; iron post stamped "1092"	1,092.787
Fox, 3.8 miles east of, 24 feet west of center of road, at fence corner, NE. ¼ sec. 20, T. 162, R. 40, on line with north-south fence; iron post stamped "1094"	1,094.457
Roseau, 0.25 mile west of main street, southwest corner of, sec. 13, T. 162 N., R. 39 W., 28 feet north of center of road on section line and 38 feet east of center of road on section line, diagonally across from Norwegian Free Church; iron post stamped "1049"	1,049.519
Roseau River; water surface, July 1, 1907	1,032.0
T. 162 N., R. 39 W., 0.37 mile south of corner of secs. 19, 20, 29, and 30, at bend of road to southeast, 84 feet east of house of Mr. Seilstrom, 25 feet east of north-south road; iron post stamped "1066"	1,066.178
Tamarack swamp in sec. 33	1,055
T. 161 N., R. 39 W., sec. 3, 2 miles west of Goos post office, in burnt clearing east of tamarack and spruce timber, 20 feet south of road and 20 feet north of large rock, in plain view; iron post stamped "1078"	1,078.431
Goos post office, 0.9 mile east of, sec. 1, T. 161 N., R. 39 W., about 45 feet southwest of corner common to secs. 1 and 36; iron post stamped "1101".	1,101.322
Pequis post office, just east of Hay Creek, southeast corner of yard fence at residence of Fred Pieper, 30 feet southeast of house and 25 feet north of center of road in sec. 26; iron post stamped "1101"	1,101.213

WARROAD QUADRANGLE.

Greenbush along highway via Badger, Roseau, and Pequis to Warroad (portion of line).

T. 162 N., R. 37 W., sec. 29, probably NE. ¼, 3.6 miles east of Pequis, 40 feet south of log cabin in clearing on claim of Alfred Otterson, 36 feet north of center of road, 1 foot south of fence; iron post stamped "1103".	1,103.665
Cedarbend post office, near NE. ¼ sec. 36, T. 162 N., R. 37 W., 75 feet west of Warroad River bank, 19 feet north of center of road, at southeast corner of garden fence, residence of Henry Stolz; iron post stamped "1103".	1,103.788
Cedarbend post office; water surface of Warroad River at, July 8, 1907	1,095
T. 162 N., R. 36 W., near line between secs. 5 and 8, 0.33 mile northeast of schoolhouse, at angle in road, 25 feet west of road and 5 feet north of corner fence post; iron post stamped "1082"	1,081.974
Warroad, at west end of lake, 39 feet southwest of crossing of Lake and State Streets, on public school grounds, 163 feet east of schoolhouse; iron post stamped "1069"	1,069.490
Lake of the Woods; water surface, July 10, 1907, range of level between 3 and 4 feet, now about medium	1,061.7
Warroad, 1,100 feet east of Lake Street crossing of Canadian Northern Railway, 145 feet east of Mr. Moody's residence, 40 feet north of edge of river and 55 feet southeast of corner of outbuilding on Mr. Moody's grounds; iron post of U. S. Engineer Corps No. 303, elevation taken on top of cap.	1,067.606
Engineer Corps elevation on assumed datum	1,012.71

Warroad along Canadian Northern Railway to Baudette (portion of line).

	Feet.
Swift flag station, 360 feet west of road crossing on township line, 40 feet north of track and 57 feet south of Warroad Mercantile Co.'s store, NE. ¼ sec. 13, T. 162 N., R. 36 W.; iron post stamped "1085"	1,085.272
Roosevelt, 156 feet west of Canadian Northern Railway station, 35 feet north of track, just west of telegraph pole; iron post stamped "1163"	1,163.227

BAUDETTE QUADRANGLE.

Warroad along Canadian Northern Railway to Baudette (portion of line).

Milepost 308, 8 feet west of, 35 feet south of track; post stamped "1181"	1,181.644
Williams station, water surface of creek at, July 17, 1907	1,135
Williams, 180 feet west of station, 70 feet east of head block at west end of switch, 43 feet south of center of track, 57 feet north of northwest corner of hotel; iron post (not stamped)	1,155.085
Graceton, 57 feet southeast of corner of station, 36 feet south of center of track, 2 feet south of telegraph pole; iron post stamped "1140"	1,140.044
Pitt flag station, 220 feet west of switch block at east end of siding, 33 feet south of center of track, 3 feet west of telegraph pole; iron post stamped "1110"	1,110.342
Winterroad River; water surface, July 20, 1907	1,077
Baudette, 650 feet east of station, on north wing wall of west abutment of Canadian Northern Railway bridge over Rainy River, set vertically in capstone; aluminum tablet stamped "1084"	1,084.282
Rainy River; water surface at Canadian Northern Railway bridge, July 22, 1907	1,062.1

Baudette along south bank of Rainy River to International Falls (portion of line).

T. 160 N., R. 30 W., corner secs. 5, 6, 7, and 8, set on south side of and in contact with corner post; iron post stamped "1093"	1,093.661
Rainy River; water surface at mouth of Rapid River, July 29, 1907	1,062.6
Rapid River, near mouth of, 64 feet northeast of corner of H. Clementson's house, 175 feet west of rapids, in exposed ledge of bedrock slightly above surface of ground; aluminum tablet stamped "1088"	1,087.976
Rapid River, water surface above rapids, about 300 feet from mouth, July 29, 1907	1,071

CLEMENTSON QUADRANGLE.

Baudette along south bank of Rainy River to International Falls (portion of line).

T. 160 N., R. 29 W., NE. ¼ sec. 5, 35 feet south of corner of house owned by S. Tornquist, 400 feet from river bank; iron post stamped "1089"	1,089.408
T. 160 N., R. 29 W., sec. 1, opposite mouth of Pine River on Canadian side, 520 feet east of house of James Pirie (deceased), 250 feet west of Henry Vog's house, close to boundary line between two places, on brow of river bank; iron post stamped "1086"	1,086.429
Black Creek, water surface at mouth of, Aug. 9, 1907	1,062.71
T. 160 N., R. 28 W., corner secs. 20, 21, 28, and 29, beside corner stake, 815 feet southwest of Mr. Murphy's store, Frontier post office, 815 feet southwest of nearest point of river bank; iron post stamped "1086"	1,086.660
T. 160 N., R. 28 W., 215 feet west of range line between Rs. 27 and 28, in sec. 25, on point of land between creek and river, opposite Bernstein's house on Canadian side, just below Boucherville, about 330 feet east of Brindle's house; iron post stamped (incorrectly) "1081"	1,082.435

	Feet.
T. 160 N., R. 27 W., on cleared land 30 feet due west of corner secs. 27, 28, 29, and 30, 1 mile north of Birchdale post office; iron post stamped "1111"	1,111.754
Rainy River; water surface at Birchdale Landing, July 20, 1907	1,063.7
T. 160 N., Rs. 26 and 27 W., on range line between secs. 31 and 36, on south side of well-cut trail or road, 85 feet south of bearing trees for meander corner at river's edge; iron post stamped "1093"	1,093.503

PELLAND QUADRANGLE.

Baudette along south bank of Rainy River to International Falls (portion of line).

T. 160 N., R. 26 W., sec. 34, 150 feet east of line between secs. 33 and 34, in large rock at water's edge, Rainy River, in rock about 6 feet long and standing 3 feet out of water; aluminum tablet stamped "1074"	1,073.932
Rainy River; water surface at Lundy's mill, opposite Barwick, Ontario, Aug. 28, 1907	1,071.6
Tps. 159 and 160 N., Rs. 25 and 26 W., near corner of, 35 feet west of range line and 15 feet north of township line; iron post stamped "1113"	1,113.004
T. 159 N., R. 25 W., NE. ¼ sec. 3, Indus post office, on brow of slope descending to river, at edge of board walk between H. Scholta's saloon and Indus Mercantile Co.'s store; iron post stamped "1106"	1,106.842
Rainy River; water surface at Indus, Sept. 3, 1907	1,075.6
T. 159 N., R. 25 W., in southwest corner sec. 23, 30 feet east of corner of secs. 22, 23, 26, and 27; iron post stamped "1097"	1,097.430
Tps. 158 and 159 N., R. 25 W., 93 feet due east of corner of secs. 2, 3, 34, and 35, 5 feet west of balsam line tree; iron post stamped "1100"	1,100.366
Black River; water surface, Sept. 11, 1907	1,077.8
T. 158 N., R. 25 W., corner secs. 11, 12, 13, and 14 (corner post not found, but its position closely located by Mr. Metcalf, farmer); iron post stamped "1098"	1,098.662
Big Fork River, water surface one-half mile above mouth, Sept. 12, 1907	1,078.6
T. 70 N., R. 26 W., NE. ¼ sec. 32, 370 feet south of bank of Rainy River at Fred Smith's place (Laurel store and post office), 40 feet east of southeast corner of Smith's barn, in fence corner; iron post stamped "1102"	1,102.375
T. 70 N., on range line between Rs. 25 and 26 W., 528 feet due north of corner of secs. 25, 30, 31, and 36; iron post stamped "1106"	1,106.132
Little Fork River; water surface, Oct. 2, 1907	1,080.7
T. 70 N., R. 25 W., corner secs. 23, 24, 25, and 26, beside corner post; iron post stamped "1124"	1,124.732

INTERNATIONAL FALLS QUADRANGLE.

Baudette along south bank of Rainy River to International Falls (portion of line).

T. 70 N., R. 24 W., 246 feet west of corner secs. 16, 17, 20, and 21, on section line; iron post stamped "1149"	1,149.694
T. 70 N. R. 24 W. SW. ¼ SE. ¼ sec. 4, 860 feet northeast of end of curve, 50 feet northwest of center of track, at clay cut, on land of Robert Irwin; iron post stamped "1152"	1,151.992
International Falls, 300 feet north of First Street, in line with Third Avenue, 180 feet southwest of edge of Rainy River, in ledge of solid rock in front of office of Maguire & Penniman (temporary); aluminum tablet stamped "1126"	1,125.976
International Falls, along bank of river on north side of Riverside drive, 10 feet south of brow of river bank, 650 feet northeast of Eighth Avenue, in line with Seventh Avenue; iron post stamped "1121"	1,121.850
Rainy River; water surface (above falls), Oct. 10, 1907	1,107.7
ainy River; water surface (below falls), Oct. 10, 1907	1,083.7

PRIMARY LEVELING.

PRIMARY LEVELS ENCIRCLING AND WITHIN THE AREA OF THE MUD LAKE DRAINAGE PROJECT.

Bagley, Bede, Bemidji, Buena Vista, Fosston, Liner, Malcolm, Roseau, Otto, Thief River Falls, and Warroad Quadrangles.

BELTRAMI, CLEARWATER, MARSHALL, POLK, RED LAKE, AND ROSEAU COUNTIES.

In the following list of standard bench marks, established by C. H. Semper in 1906, no figures of elevation were stamped upon the posts.

THIEF RIVER FALLS QUADRANGLE.

Thief River Falls east to Beltrami County line (portion of line).

	Feet.
T. 154 N., Rs. 42 and 43 W., corner of secs. 25, 30, 31, and 36; iron post...	1, 131. 339
Tps. 153 and 154 N., R. 42 W., corner of secs. 4, 5, 32, and 33; iron post...	1, 137. 476
Tps. 153 and 154 N., R. 42 W., corner of secs. 1, 2, 35, and 36; iron post...	1, 150. 719

LINER QUADRANGLE.

Thief River Falls east to Beltrami County line (portion of line).

Tps. 153 and 154 N., R. 41 W., corner of secs. 4, 5, 32, and 33; iron post...	1, 157. 154
Tps. 153 and 154 N., R. 41 W., corner of secs. 1, 2, 35, and 36; iron post...	1, 166. 466
Tps. 153 and 154 N., R. 40 W., corner of secs. 4, 5, 32, and 33; iron post...	1, 174. 297
Tps. 153 and 154 N., R. 40 W., corner of secs. 1, 2, 35, and 36; iron post...	1, 178. 579
Tps. 153 and 154 N., R. 39 W., corner of secs. 4, 5, 32, and 33; iron post (northwest corner of crossroad)..	1, 183. 195
Tps. 153 and 154 N., R. 39 W., corner of secs. 1, 2, 35, and 36, 33 feet south of large granite bowlder; iron post. (Note: Ground very boggy and bench mark loose)..	1, 182. 884

Thief River Falls north along range line to McPhail.

T. 154 N., Rs. 38 and 39 W., corner of secs. 24, 25, 19 and 30 (no section post); iron post..	1, 185. 916
T. 154 N., R. 39 W., SE., ¼ sec. 1, 150 feet east of N. J. Jorgenson's house, at barnyard fence (no section corner found); iron post..................	1, 184. 490

MALCOLM QUADRANGLE.

McPhail east to Sand Ridge.

T. 155 N., R. 38 W., corner of secs. 29, 30, 31, and 32, near wire fence; iron post..	1, 189. 232
T. 155 N., R. 38 W., corner of secs. 26, 27, 34, and 35; iron post..........	1, 196. 149
T. 155 N., R. 37 W., corner of secs. 29, 30, 31, and 32, near wire fence line; iron post..	1, 207. 448
T. 155 N., R. 37 W., corner of secs. 26, 27, 34, and 35; near wire fence line; iron post..	1, 212. 558
T. 155 N., R. 36 W., corner of secs. 19, 20, 29, and 30; iron post..........	1, 225. 684
T. 155 N., R. 36 W., center of sec. 27, 35 feet north of quarter corner; iron post..	1, 230. 631

Sand Ridge north 8 miles, thence west to Malcolm.

T. 155 N., R. 36 W., NE. ¼ sec. 14, at north end of Sand Ridge, east end of clearing, 25 feet east of large poplar tree; iron post......................	1, 245. 850
T. 156 N., R. 36 W., corner of secs. 15, 16, 21, and 22, near fence line; iron post..	1, 239. 234

	Feet.
T. 156 N., Rs. 36 and 37 W., corner of secs. 13, 18, 19, and 24, near fence line; iron post	1,229.316

Malcolm west via Grygla to Liner, thence north to Gatzke (portion of line).

T. 156 N., R. 37 W., corner of secs. 22, 23, 26, and 27; iron post	1,224.736
T. 156 N. R. 37 W., northwest corner of NE. ¼ sec. 31, northwest corner of Ole Baklund's farm; iron post	1,210.560

LINER QUADRANGLE.

Malcolm west via Grygla to Liner, thence north to Gatzke (portion of line).

T. 155 N., R. 38 W., sec. 2, 768 feet north of Carmel post office; iron post	1,202.047
Tps. 155 and 156 N., R. 38 W., corner of secs. 5, 6, 31, and 32, at northwest corner of fence; iron post	1,187.225
T. 156, R. 39 W., southeast corner of sec. 26, Grygla post office, A. O. Fladeland's yard; iron post	1,179.069
T. 156, R. 39 W., sec. 19, 110 feet southeast of store at Liner post office, at corner of wire fence; iron post	1,166.978
T. 157 N., R. 40 W., NE. ¼ sec. 36, on John Saxvold's farm; iron post	1,172.356
T. 157 N., R. 40 W., corner of secs. 11, 12, 13, and 14, west side of road; iron post	1,183.042

Gatzke west to Middle River (portion of line).

T. 157 N., R. 40 W., corner of secs. 3, 4, 9, and 10, south side of road; iron post	1,181.644
Thief Lake; water surface, Oct. 13, 1906	1,163.1
T. 157 N., Rs. 40 and 41, W., corner of secs 1, 6, 7, and 12, north side of road; iron post	1,173.830
T. 157 N., R. 41 W., corner of secs. 3, 4, 9, and 10, on north side of road; iron post	1,155.770
Thief River; water surface, Oct. 13, 1906, at section line between secs. 5 and 8	1,147.8
T. 157 N., R. 41 W., at quarter corner between secs. 6 and 7; iron post	1,154.917

THIEF RIVER FALLS QUADRANGLE.

Gatzke west to Middle River (portion of line).

T. 157 N., R. 42 W., corner of secs. 9, 10, 15, and 16; iron post	1,154.308
T. 157 N., Rs. 42 and 43 W., corner of secs. 7, 12, 13, and 18; iron post	1,144.245

The elevations in the following list were obtained as the result of primary leveling in the fall of 1906, by A. P. Meade, jr., Paul Funderhide, and R. P. Thompson. None of the bench marks have elevations stamped upon them.

Thief River Falls to Thorwick.

	Feet.
T. 154 N., R. 43 W., corner of secs. 22, 23, 26, and 27; iron post	1,129.781
T. 154 N., Rs. 42 and 43 W., corner secs. 7, 12, 13, and 18; iron post	1,139.671
Tps. 154 and 155 N., Rs. 42 and 43, west corner of secs. 1 and 36, on range line; iron post	1,142.090

Thorwick to Mud Lake.

T. 155 N., R. 42 W., corner of secs. 18 and 19, on range line; iron post	1,139.190
Tps. 155 and 156 N., R. 42 W., corner of secs. 4, 5, 32, and 33; iron post	1,139.513
Elm Lake; water surface, Aug. 31, 1906	1,143.0
Mud Lake; water surface, Sept. 2, 1906	1,140.9

Thorwick east to Germantown and northeast to Liner (portion of line).

	Feet.
Tps. 154 and 155 N., R. 42 W., corner of secs. 3, 4, 33, and 34, 35 feet northwest of; iron post	1,148.253

LINER QUADRANGLE.

Thorwick east to Germantown and northeast to Liner (portion of line).

Tps. 154 and 155 N., Rs. 41 and 42 W., corner of secs. 1, 6, 31, and 36, 60 feet south of; iron post	1,150.760
Germantown, corner of William Vaughan's house; iron post	1,158.428
T. 155 N., Rs. 40 and 41 W., quarter corner between secs. 13 and 18, 300 feet north of; iron post	1,155.736
T. 156 N., R. 40 W., SW. ¼ sec. 34; iron post	1,160.150

On Germantown and Grygla road.

T. 155 N., R. 40 W., NW. ¼ sec. 22, near bridge; iron post	1,163.184

Other scattering bench marks.

T. 158 N., R. 40 W., in southwest corner of sec. 14, at forks of Randen Road and trail north; iron post	1,206.566
Erie post office, T. 153 N., Rs. 39 and 40 W., corner of secs. 13, 18, 19, and 24; iron post	1,169.465
Tps. 152 and 153 N., R. 39 W., corner of township line common to secs. 33 and 34; iron post	1,167.734
T. 157 N., Rs. 38 and 39 W., corner of secs. 1, 6, 7, and 12; iron post	1,182.215
T. 158 N., R. 40 W., between secs. 27 and 28, at corner of fence opposite house, 40 feet south of Moose River. Established in 1907; no elevation stamped	1,166.497

ROSEAU QUADRANGLE.

Scattering bench marks.

T. 159 N., R. 39 W., sec. 34, probably in NE. ¼, along road going up Roseau River, about 400 feet southeast of vacant cabin, between river and road at bridge crossing river; iron post	1,179.307
T. 160 N., Rs. 38 and 39 W., corner of secs. 1, 6, 7, and 12; iron post. (This elevation is in doubt within limit of 1 foot)	1,107.86
T. 159 N., R. 39 W., SE. ¼ sec. 18, on east side of road 300 feet north of old Casperson post-office, at bridge crossing Roseau River; iron post	1,149.73

WARROAD QUADRANGLE.

Scattering bench marks.

T. 161 N., R. 35 W., SW. ¼ sec. 35, 150 feet east of Jack Meise's cabin, 500 feet east of section line, and about 200 feet north of county line between Roseau and Beltrami Counties; iron post	1,227.53
T. 159 N., R. 36 W., SW. ¼ sec. 14, on old Government inspector's trail; iron post	1,268.09
T. 159 N., R. 37 W., near center of sec. 17, at junction of trails, one north, one up Roseau River; iron post	1,225.27

BEDE QUADRANGLE.

Spur line—Loman up Black River.

T. 158 N., R. 25 W., corner of secs. 28. 29, 32, and 33, 8 inches west of corner post; iron post stamped "1135"	1,135.804
T. 158 N., Rs. 26 and 27 W., corner of secs. 19, 30, 24, and 25, 1.5 feet west of corner post; iron post stamped "1144"	1,144.868

BEMIDJI QUADRANGLE.

Bemidji along Minneapolis, Red Lake & Manitoba Railway to Red Lake (portion of line).

	Feet.
Bemidji, Mississippi River Commission bench mark, 800 feet west of Great Norther Railway station, in corner of E. J. Willett's yard, on west side of Irving Avenue, north of Great Northern right of way; cap on top of iron post	1,363.178
T. 146 N., Rs. 33 and 34 W., 60 feet southeast of corner of secs. 6, 7, 1, and 12, corner of wire fence, 325 feet north of Great Northern Railway (corner stake not found); iron post stamped "1387 Minnesota"	1,387.210

BUENA VISTA QUADRANGLE.

Bemidji along Minneapolis, Red Lake & Manitoba Railway to Red Lake (portion of line).

Marsh flag station, 27 feet east of platform, 40 feet east of center of track, directly opposite flag station signboard, 80 feet north of switch stand at south end of siding; iron post stamped "1402 Minnesota"	1,401.922
Werner flag station (Campbell Lake), 50 feet east of center of track and opposite station platform, 150 feet south of road crossing; iron post stamped "1371 Minnesota"	1,371.579
Campbell Lake; water surface, October 19, 1907	1,354.7
Puposky station, 275 feet southeast of, at northeast corner of block 13, Puposky town site, in exact position of corner stake, 180 feet east of railroad track and in front of house of A. E. Hodgson; iron post stamped "1368 Minnesota"	1,367.972
Mud Lake; water surface, October 27, 1907	1,354.8
T. 149 N., R. 33 W., corner of secs. 15, 16, 21, and 22, 65 feet east of railroad track, 70 feet north of center of platform at Neeley siding flag station; iron post stamped "1382 Minnesota." (Exact corner not found, but location is close according to bearing trees)	1,382.189
Nebish station, 0.4 mile north of, 365 feet north of switch stand at point of spur south to station, 50 feet west of center of track, on rise of ground about level with track, in front of buildings of John Lauk in NW. ¼ sec. 27; iron post stamped "1351 Minnesota"	1,350.874
Nebish Lake; water surface, October 23, 1907	1,354.2
Nebish station, 4.33 miles north of, 2,000 feet north of milepost 29, at south end of cut near old abandoned log camp, 28 feet west of center of tracks and 0.6 foot lower than top of rail, on steep side hill, probably in NE. ¼ sec. 8; iron post stamped "1274 Minnesota"	1,274.361
Redby station, 0.4 mile south of, 460 feet south of roundhouse and opposite switch stand, at south end of Y, 60 feet west of center of track and 2.5 feet lower than top of rail; iron post stamped "1229 Minnesota"	1,229.261
Red Lake; water surface, October 25, 1907	1,176.2

Redby around east end of Red Lake via Quiring, Foy, and Shotley to Tamarack River (portion of line).

T. 151 N., R. 32 W., sec. 30, near south boundary and approximately 0.25 mile west of southeast corner of, 500 feet east of Hay Creek, at abandoned lumber camp, in open grassy land, 150 feet south of largest log building in camp just on north side of an east-west log fence, in line with a log fence running south, 3 feet north of bars through fence; iron post stamped "1221 Minnesota"	1,221.556

	Feet.
T. 151 N., R. 32 W., northeast corner sec. 27, 0.12 mile south of section corner, 250 feet west of section line, inside of yard fence at residence of D. W. Carter (Quiring post office), 40 feet south of east end of house; iron post stamped "1202 Minnesota"	1,201.920
Tps. 151 and 152 N., R. 32 W., corner of secs. 2, 3, 34, and 35, in position of corner stake in low swampy ground, 950 feet north of Cormorant Creek; iron post stamped "1179 Minnesota"	1,178.961
NOTE.—This post is liable to settlement as it settled ¼ inch under two blows with iron bar after being well tamped and set. Ground is soft.	
T. 152 N., R. 32 W., SE. ¼ SW. ¼ sec. 27, Battle River post office, residence of Joseph Peronie, 3.5 feet south and 3 feet east of southwest corner of store, 160 feet east of Indian reservation line; iron post stamped "1188"	1,187.901
T. 152 N., R. 31 W., 43 feet N. 27° E. (magnetic bearing) from southwest corner sec. 18, about 350 feet north of Saum post office and store; iron post stamped "1192 Minnesota"	1,192.729
T. 152 N., R. 31 W., 225 feet N. 45° W. (magnetic bearing) from quarter corner between secs. 6 and 7, 48 feet south of front of house of John Carlson (Foy post office), 4 feet south of yard fence; iron post stamped "1199 Minnesota"	1,198.869

OTTO QUADRANGLE.

Redby around east end of Red Lake via Quiring, Foy, and Shotley to Tamarack River (portion of line).

T. 153 N., R. 31 W., corner of secs. 19, 20, 29, and 30 (exact position of corner stake, which was lying on ground, could not be determined, but post must be within 3 or 4 feet of corner); iron post stamped "1212 Minnesota"	1,212.015
T. 153 N., R. 31 W., 22 feet northwest of corner of secs. 9, 10, 15, and 16, 10 feet northwest of oak bearing tree which is 2 feet in diameter; iron post stamped "1183 Minnesota"	1,183,542
T. 154 N., R. 31 W., sec. 36, 30 feet west of range line on bank of lake, 125 feet north of schoolhouse and in line with northeast side of building, about 400 feet southwest of Domaas post office; iron post stamped "1183 Minnesota"	1,183.566
T. 154 N., R. 30 E., NE. ¼ sec. 8, on north bank of Tamarack River, near its mouth, 70 feet north of river bank, 15 feet east of an oak tree which is most southerly on first ridge from beach, 28 feet north of an old log cabin; iron post stamped "1183 Minnesota"	1,183.035
T. 155 N., R. 31 W., SE. ¼ sec. 36, 500 or 600 feet north of Red Lake, 150 feet west of Moose Creek, on firm ground in birch and balsam timber, 20 feet east of small log cabin; iron post stamped "1182 Minnesota"	1,182.792

The elevations in the following list were obtained as the result of primary leveling in 1908 by A. P. Meade, jr., and Paul Funderhide.

BUENA VISTA QUADRANGLE.

Puposky west via Fowlds, Aure, Winsor, Gully, and Espetvet to Rhoda (portion of line).

	Feet.
T. 149 N., R. 34 W., Fowlds station, road crossing at, foot of telephone pole on west side of track; iron post marked "1391"	1,391.611
T. 149 N., R. 34 W., sec. 32; water surface of lake	1,372
T. 149 N., R. 35 W., sec. 35; water surface of Sandy Lake	1,354

BAGLEY QUADRANGLE.

Puposky west via Fowlds, Aure, Winsor, Gully, and Espetvet to Rhoda (portion of line).

	Feet.
T. 148 N., R. 35 W., northeast corner of sec. 4, 300 feet west of (Aure post office); iron post stamped "1420"	1,420.510
T. 148 N., R. 36 W., NW. ¼ sec. 2, 300 feet east of cabin and 600 feet west of barn; iron post stamped "1483"	1,483.082
T. 149 N., R. 36 W., 700 feet south of quarter corner between secs. 32 and 33; iron post stamped "1472"	1,472.275
T. 149 N., R. 37 W., corner of secs. 22, 23, 26, and 27, at northeast fence corner of crossroads; iron post stamped "1331"	1,331.109
Ruffy Brook; water surface near last-mentioned post	1,314.9
Ruffy Brook; water surface in sec. 15	1,293
T. 149 N., R. 37 W., near corner of secs. 4, 5, 8, and 9, one-quarter mile north of Leon post office, at northwest corner of crossroads, at foot of fence and opposite schoolhouse; iron post stamped "1241"	1,241.100
Ruffy Brook; water surface in sec. 5	1,231
T. 149 N., R. 38 W., Lost River, water surface on line between secs. 1 and 12.	1,227
T. 150 N., R. 38 W.; water surface of lake in sec. 35	1,193

FOSSTON QUADRANGLE.

Puposky west via Fowlds, Aure, Winsor, Gully, and Espetvet to Rhoda (portion of line).

T. 150 N., R. 38 W., Winsor post office, near quarter corner between secs. 27 and 28, at southeast fence corner opposite store and at road forks; iron post stamped "1215"	1,215.453
T. 150 N., R. 39 W., Gully post office, SW. ¼ sec. 26, at fence corner, forks of road, opposite store; iron post stamped "1223"	1,223.689
T. 150 N., R. 40 W., sec. 9, Espetvet post office, at northeast corner of store building; iron post stamped "1150"	1,150.477
Lost River; water surface near Espetvet	1,142
T. 151 N., R. 40 W., near corner of secs. 3, 4, 9, and 10, at fence corner in sec. 10; iron post stamped "1161"	1,161.498
T. 152 N., R. 40 W., sec. 33, water surface of Clear Water River at bridge.	1,151
T. 152 N., R. 40 W., near corner of secs. 8, 9, 17, and 16, one-half mile north of Rhoda post office, at fence corner; iron post stamped "1158"	1,158.816

Ashby, Barrett, Battle Lake, Chokio, Fergus Falls, Herman, Morris, Rothsay, Underwood, and Wendell quadrangles.

GRANT, OTTERTAIL, AND STEVENS COUNTIES.

The elevations in the following list were determined by primary leveling extended from the precise-level line of the Coast and Geodetic Survey which crosses the Barrett, Herman, Ashby, Wendell, and Fergus Falls quadrangles. The work of 1910 is a continuation of that done in 1909. The elevations accord with the 1907 adjustment.

The leveling was done as follows: In Morris quadrangle, in 1909, by G. E. Halstead; in Barrett and Herman quadrangles, in 1909, by C. R. Beckler; in Chokio quadrangle, in 1909, by G. E. Halstead, and in 1910, by E. C. Bibbee; in Ashby quadrangle, in 1910, by J. M. Ray; in Wendell quadrangle by C. R. Beckler in 1909 and by J. M. Ray and E. C. Bibbee in 1910; and in Fergus Falls, Rothsay, Underwood, and Battle Lake quadrangles by J. M. Ray and E. C. Bibbee in 1910.

WENDELL QUADRANGLE.

Point 2.5 miles west of Hereford, south to sec. 10, T. 129 N., R. 44 W.

	Feet.
Hereford, 2.5 miles west of, 30 feet south of Great Northern Railroad, 0.5 mile west of grade crossing at the right-of-way line, west side of private road crossing; iron pipe (Coast and Geodetic Survey bench mark)	1,030.100

Point 2.5 miles west of Hereford along highway, west 2.5 miles, thence north 15.5 miles, thence east 1 mile, thence north 2 miles, thence east to point 0.7 mile east of Dayton Dam, thence southwest to sec. 1, T. 131 N., R. 44 W., thence south 10.5 miles and east to Wendell, thence south 1.2 miles.

	Feet.
T. 130 N., R. 44 W., in southeast corner of sec. 31, 15 feet west and 25 feet north of center of crossroads; iron post stamped “1013”	1,013.398
T. 130 N., R. 44 W., in southeast corner of sec. 18, 50 feet west by 35 feet north of center of crossroads; iron post stamped “1019”	1,019.444
T. 131 N., R. 44 W., in southeast corner of sec. 31, 30 feet north by 30 feet west of center of crossroads; iron post stamped “1028”	1,028.391
T. 131 N., R. 44 W., in southwest corner of sec. 17, 25 feet north by 25 feet east of center of crossroads; iron post stamped “1044”	1,043.555
T. 132 N., R. 44 W., southeast corner of sec. 31, 15 feet north by 35 feet west of center of T road south; iron post stamped “1049”	1,048.755
T. 132 N., R. 44 W., in southeast corner of sec. 20, 20 feet west by 25 feet north of center of crossroads, in southeast corner of school lot; iron post stamped “1061”	1,061.286
T. 132 N., R. 44 W., in southeast corner of sec. 23, 30 feet west by 20 feet north of center of crossroads; iron post stamped “1088”	1,088.433
Dayton dam, top of iron bolt in concrete masonry work, east end and north side of dam, third bolt from east end	1,112.543
T. 132 N., R. 43 W., at quarter corner north side of sec. 32, 60 feet northwest of residence of C. A. Littsen, 150 feet southwest of schoolhouse at T road north; iron post stamped “1171”	1,170.845
T. 131 N., R. 44 W., at quarter corner east side of sec. 1, 30 feet west by 30 feet south of center of intersection of T road south; iron post stamped “1126”	1,126.010
T. 131 N., R. 43 W., in southwest corner of sec. 19, 35 feet north by 20 feet east of center of crossroads; iron post stamped “1114”	1,114.136
T. 131 N., R. 43 W., in southwest corner of sec. 30, 240 feet southwest of farm house, in base of small boxelder tree; spike	1,130.95
T. 130 N., R. 43 W., in southwest corner of sec. 6, 25 feet east by 25 feet north of center of crossroads; iron post stamped “1124”	1,123.901
T. 130 N., R. 43 W., in northwest corner of sec. 30, 20 feet west of center of intersection of T road east, on east side of Ash Lake; iron post stamped “1080”	1,080.025
Wendell, in northwest corner of public school lot, 100 feet northwest of public school building; iron post stamped “1151”	1,150.768
Wendell, 1.8 kilometers south of, 3.5 kilometers east of Hereford, 25 meters north of railroad, at right of way, west highway line, and southeast corner of meadow belonging to Arthur Smith; iron post (Coast and Geodetic Survey bench mark B-2)	1,130.114

Point 1.2 miles south of Wendell east along highway 2 miles, thence north 10.5 miles.

	Feet.
T. 130 N., R. 43 W., northeast corner of sec. 34, 25 feet south by 25 feet west of center of crossroads; iron post stamped “1118”	1,118.131
T. 130 N., R. 43 W., in northwest corner of sec. 14, 25 feet south by 25 feet east of center of crossroads; iron post stamped “1148”	1,147.629

	Feet.
T. 131 N., R. 43 W., northeast corner of sec. 34, 30 feet south by 20 feet west of center of crossroads; iron post stamped "1146"	1,146.191
T. 131 N., R. 43 W., in northwest corner of sec. 14, 15 feet east by 30 feet south of center of crossroads; iron post stamped "1192"	1,192.331

Southeast corner of sec. 20, T. 132 N., R. 44 W., north along highways to southwest corner of sec. 10, T. 132 N., R. 44 W.

T. 132 N., R. 44 W., in southeast corner of sec. 20, 20 feet west by 25 feet north of center of crossroads, in southeast corner of school lot; iron post stamped "1061"	1,061.286
T. 132 N., R. 44 W., 30 feet south by 25 feet east of southwest corner of sec. 10; iron post stamped "1094"	1,093.969

BARRETT QUADRANGLE.

Thorsborg south along highway to county line at southeast corner of sec. 1, T. 126 N., R. 42 W.

Thorsborg, Grant County, Sanford Township, on NW. ¼ sec. 13, 110 meters north and 60 meters west of railway station, at southwest corner of pasture belonging to Henry Lajord, at northeast corner of crossroads, 10 meters east and 5 meters north of line of travel; iron pipe (Coast and Geodetic Survey bench mark V-1)	1,204.971
T. 129 N., R. 42 W., in southeast corner of SW. ¼ sec. 24, at northwest corner of crossroads, 5 feet west of line of travel, on granite bowlder; chiseled square, marked "1247"	1,246.90
T. 129 N., R. 42 W., in southwest corner of SE. ¼ sec. 36, 25 feet north by 25 feet east of center of crossroads; iron post stamped "1212"	1,212.460
Barrett, in front of station; top of east rail; marked on face of platform "1168.0"	1,168.0
Barrett, in south end of west doorsill (sandstone) of the Barrett public school building; aluminum tablet stamped "1168"	1,168.300
T. 128 N., R. 41 W., in northwest corner of sec. 31, 25 feet north by 25 feet east of center of intersection of T road east; iron post stamped "1179"	1,179.380
T. 127 N., R. 41 W., in northwest corner of sec. 6, at crossroads, top of iron section corner post	1,175.15
T. 127 N., R. 41 W., in northwest corner of sec. 18, 30 feet east by 30 feet south of center of line of travel; iron post stamped "1183"	1,183.421
T. 127 N., R. 41 W., in northwest corner of sec. 31, 40 feet east by 25 feet south of center of T road east; iron post stamped "1178"	1,178.247

Southeast corner of sec. 32, T. 127 N., R. 41 W., east along county line road 3 miles, thence north along highway to Erdahl.

T. 127 N., R. 41 W., in southeast corner of sec. 32, 30 feet west by 20 feet south of center of crossroads; iron post stamped "1133"	1,232.960
T. 127 N., R. 41 W., in southeast corner of sec. 35, 25 feet west by 25 feet north of crossroads; iron post stamped "1232"	1,232.121
T. 127 N., R. 41 W., in center of south side of SE. ¼ of sec. 14, 25 feet west by 25 feet north of center of T road west; iron post stamped "1193"	1,193.484
Hoffman, in south end of west doorsill (sandstone) of the Hoffman public school building; aluminum tablet stamped "1256"	1,255.901
Hoffman, 1.4 miles north of, on west side of road, 10 feet from center of line of travel; point on granite bowlder	1,233.79
T. 128 N., R. 41 W., in northeast corner of SE. ¼ sec. 26, 55 feet south of center of line of travel at right angle in road; iron post stamped "1234"	1,234.423
T. 128 N., R. 41 W., in northwest corner of sec. 14, 20 feet east by 20 feet south of center of T road east; iron post stamped "1252"	1,251.993

	Feet.
T. 129 N., R. 41 W., in southwest corner of sec. 25, 35 feet east by 30 feet north of center of T road east; iron post stamped "1236"	1,235.921
Erdahl (Cork P. O.), Grant County, on land of T. Tobiason, of Ashby, at the east line of main street, 58 meters south of railway, at a point 70 meters west of station, 7 meters east of line of travel, 17 meters northeast of frame store of A. J. Okelgren, 24 meters south of grain elevator; iron post (Coast and Geodetic Survey bench mark U-1)	1,266.757

Southwest corner of sec. 19, T. 127 N., R. 41 W., west along highway 1.5 miles, thence south 1 mile, thence west 3 miles, thence north to Elbow Lake.

T. 127 N., R. 42 W., near quarter corner north side of sec. 26, on foundation stone of schoolhouse (district No. 16) at northeast corner; chiseled square.	1,188.07
T. 127 N., R. 42 W., in northeast corner of sec. 34, 35 feet west by 35 feet south of center of crossroads; iron post stamped "1197"	1,196.775
T. 127 N., R. 42 W., in southeast corner of sec. 30, in southeast corner of school lot, 30 feet west by 30 feet north of center of crossroads; iron post stamped "1147"	1,146.592
T. 127 N., R. 42 W., in northwest corner of sec. 20, 35 feet south by 38 feet east of center of crossroads, on stone bowlder; chiseled square	1,152.97
T. 127 N., R. 42 W., 40 feet west by 25 feet south of center of crossroads; iron post stamped "1146"	1,145.547
T. 128 N., R. 42 W., in northwest corner of sec. 32, 30 feet east by 20 feet south of center of crossroads; iron post stamped "1156"	1,156.075
T. 128 N., R. 42 W., in northeast corner of sec. 18, 25 feet west by 20 feet south of center of crossroads, near Huset Church; iron post stamped "1178"	1,177.367
T. 129 N., R. 42 W., in southeast corner of sec. 29, 30 feet west by 20 feet north of center of crossroads; iron post stamped "1162"	1,162.034
Elbow Lake, Grant County, in the north end of south doorsill (sandstone) of the First National Bank building, 1.8 meters north of south side of building, 0.1 meter from east of front edge of sill, 0.08 meter south of brickwork, 0.4 meter above sidewalk, 0.5 meter north of center of doorway; red metal disk (Coast and Geodetic Survey bench mark X-1)	1,213.903

HERMAN QUADRANGLE.

Wendell south along highway to northwest corner of sec. 4, T. 128 N., R. 43 W., thence east to sec. 5, T. 128 N., R. 42 W.

T. 129 N., R. 42 W., in northwest corner of sec. 28, 20 feet south by 30 feet east of center of crossroads; iron post stamped "1106"	1,106.155
T. 128 N., R. 43 W., in northwest corner of sec. 2, in southeast corner of bridge abutment, bridge spanning Mustinka River; aluminum tablet stamped "1091"	1,091.189
T. 129 N., R. 43 W., at northeast corner of sec. 1, on quarter line of sec. 31; monument	1,161.75

Northwest corner of sec. 4, T. 128 N., R. 43 W., south along highway to southeast corner of sec. 16, T. 127 N., R. 43 W., thence east to sec. 30, T. 127 N., R. 42 W.

T. 128 N., R. 43 W., 0.2 mile south of northwest corner of sec. 9, 25 feet east of center line of travel; iron post stamped "1100"	1,100.304
T. 128 N., R. 43 W., in southwest corner of sec. 8, in base of tree on west side of road, 20 feet west of center line of travel; spike	1,100.44
T. 128 N., R. 43 W., in northwest corner of SW. ¼ sec. 21, 20 feet east of center of line of travel; iron post stamped "1089"	1,089.415
T. 128 N., R. 43 W., in southwest corner of sec. 22, on granite bowlder at T road west; chiseled square	1,107.94

	Feet.
T. 127 N., R. 43 W., in northeast corner of sec. 4, 30 feet west by 15 feet south of center of crossroads; iron post stamped "1100"	1,099.881
T. 127 N., R. 43 W., in southeast corner of sec. 23, 35 feet west by 25 feet north of center of crossroads; iron post stamped "1128"	1,128.226

Southeast corner of sec. 16, T. 127 N., R. 43 W., west along highway 4.5 miles, thence south to county line.

T. 127 N., R. 43 W., in sec. 21, 30 feet north by 35 feet south of respective lines of travel at road fork; iron post stamped "1093"	1,093.243
T. 127 N., R. 43 W., at corner of secs. 13, 24 (T. 127 N., R. 44 W.) and secs. 18 and 19 (T. 127 N., R. 43 W.), in center of line of travel at crossroads; iron stake	1,075.44
Herman, in north end of west doorsill (sandstone) of the Grant County State Bank; aluminum tablet stamped "1076"	1,075.546
Herman, in front of station; top of east rail	1,074.9

County line northwest corner of sec. 4, T. 126 N., R. 44 W., indirectly north along highway to southwest corner of sec. 10, T. 129 N., R. 44 W.

T. 126 N., R. 44 W., in northwest corner of sec. 4, 30 feet east by 25 feet south of center of crossroads; iron post stamped "1057"	1,057.267
T. 127 N., R. 44 W., in southeast corner of sec. 29, on granite bowlder at crossroads; chiseled square	1,054.95
T. 127 N., R. 44 W., in northwest corner of sec. 20, 30 feet south of center of intersection at T road north; iron post stamped "1046"	1,045.130
T. 127 N., R. 44 W., in northeast corner of sec. 7, 100 feet south by 50 feet west of center of crossroads; on granite bowlder; chiseled square	1,035.73
T. 127 N., R. 44 W., in northwest corner of sec. 5, 30 feet south by 30 feet east of center of crossroads; iron post stamped "1032"	1,031.790
T. 128 N., R. 44 W., in southwest corner of sec. 16, 25 feet east by 35 feet north of center of crossroads, 840 feet east of Great Northern Railway, about 1.5 miles northwest of Norcross; iron post stamped "1029"	1,028.564
T. 129 N., R. 44 W., in southeast corner of sec. 33, 50 feet north by 25 feet west of center of T road north; iron post stamped "1024"	1,023.378
T. 129 N., R. 44 W., in northwest corner of sec. 22, 40 feet south by 30 feet east of center of crossroads; iron post stamped "1025"	1,024.807

Herman north along highway 6 miles, thence west to point 1.5 miles northwest of Norcross.

T. 127 N., R. 44 W., in northeast corner of sec. 2, in base of cottonwood tree on west side of Y road; spike	1,073.56
T. 127 N., R. 44 W., in northwest corner of sec. 1, 20 feet east by 20 feet south of center of crossroads; iron post stamped "1056"	1,056.035
T. 128 N., R. 44 W., in southeast corner of sec. 14, 35 feet north by 35 feet west of center of crossroads; iron post stamped "1052"	1,051.548
T. 128 N., R. 44 W., in southwest corner of sec. 16, 35 feet north by 25 feet east of center of crossroads; iron post stamped "1029"	1,028.564

MORRIS QUADRANGLE.

Sec. 1, T. 126 N., R. 42 W., south along highway and Great Northern Railway to southwest corner of sec. 25, T. 124 N., R. 42 W., thence east along highway 6 miles and north to county line.

T. 126 N., R. 41 W., in northwest corner of sec. 19, 23 feet east of center line of travel at road intersection, 3 feet south of east-west fence line; iron post stamped "1153"	1,153.343
T. 126 N., R. 42 W., in southeast corner of sec. 25, 36 feet north by 9 feet west of center of road intersection, in base of 12-inch poplar tree; spike	1,121.56

	Feet.
T. 125 N., R. 41 W., in northwest corner of sec. 6, 18 feet south by 17 feet east of center of crossroads; iron post stamped "1129"	1,129.316
T. 125 N., R. 42 W., northeast of center of sec. 24, 91 feet south of east-west fence line, 15 feet east of center of line of travel, 40 feet southeast of signpost 8 inches in diameter; iron post stamped "1138"	1,137.461
T. 125 N., R. 42 W., southwest corner of sec. 24, at base of fence post at jog in road to west, on ½-inch bump on bowlder (5 feet around)	1,138.57
T. 125 N., R. 42 W., in southeast corner of NE. ¼ sec. 35, in base of telegraph pole at road intersection and railroad crossing, 15 feet south of fence line, 50 feet northwest of railroad crossing; three nails	1,128.24
Morris, southwest corner of Citizens Bank, east of entrance, in water table; aluminum tablet stamped "1138"	1,137.926
T. 124 N., R. 42 W., in southwest corner of sec. 13, 12 feet east by 11 feet north of center of road intersection; iron post stamped "1078"	1,078.148
T. 124 N., R. 42 W., in southwest corner of sec. 25, 32 feet east by 46 feet north of center of crossroads; iron post stamped "1125"	1,124.441
T. 124 N., R. 41 W., in southeast corner of SW. ¼ NE. ¼ sec. 29, 20 feet north by 30 feet west of center of crossroads; iron post stamped "1163"	1,163.181
T. 124 N., R. 41 W., in northeast corner of NW. ¼ sec. 35, 18 feet west by 30 feet south of center of road intersection, 0.5 mile east by 1 mile north of Hancock; iron post stamped "1161"	1,160.622
T. 124 N., R. 41 W., in southeast corner of sec. 10, 35 feet west by 25 feet north of center of intersection, 10 feet west of north-south fence line; iron post stamped "1175"	1,175.066
T. 125 N., R. 41 W., in southeast corner of sec. 34, 20 feet north of red granary, 120 feet east by 53 feet north of fence line, on 24-inch rock; ⅞-inch knob	1,149.02
T. 125 N., R. 41 W., in northwest corner of sec. 35, 358 feet south of section line, 16 feet east of center of road, 9 feet southwest of telephone pole; iron post stamped "1150"	1,149.928
T. 125 N., R. 41 W., in southeast corner of NE. ¼ SW. ¼ sec. 14, 15 feet west by 100 feet north of center of road intersection, 70 feet north of sign; iron post stamped "1158"	1,158.042
T. 125 N., R. 41 W., in southwest corner of sec. 1, 16 feet north by 51 feet east of center of road at intersection; iron post stamped "1173"	1,172.455
T. 126 N., R. 41 W., in southeast corner of sec. 26, 90 feet north by 32 feet west of center of road, on north part of 18-inch by 28-inch rock; 1-inch knob	1,183.76
T. 126 N., R. 41 W., in southeast corner of sec. 23, 10 feet west by 70 feet north of center of road, on 15-foot by 28-inch rock; 1-inch knob	1,176.77
T. 126 N., R. 41 W., in northeast corner of sec. 23, 33 feet west by 45 feet south of center of crossroads; iron post stamped "1170"	1,169.755
T. 127 N., R. 41 W., in southeast corner of sec. 35, 25 feet west by 25 feet north of center of crossroads; iron post stamped "1232"	1,232.121

Southwest corner of sec. 13, T. 124 N., R. 42 W., west, south, and west along highway to southwest corner of sec. 19, T. 124 N., R. 42 W., thence northeast, north, and west to southwest corner of sec. 31, T. 125 N., R. 42 W.

T. 124 N., R. 42 W., in northwest corner of sec. 27, 25 feet south by 25 feet east of center of crossroads, in top of concrete post; aluminum tablet stamped "1122"	1,121.824
T. 124 N., R. 42 W., in southwest corner of sec. 19, 25 feet east by 35 feet north of center of crossroads, in top of concrete post; aluminum tablet stamped "1158"	1,157.450

	Feet.
T. 124 N., R. 42 W., in southeast corner of sec. 7, on north side of east abutment of bridge; 1-inch knob	1,081.11
T. 124 N., R. 42 W., in southeast corner of sec. 6, 40 feet north by 22 feet west of center of road intersection, in top of concrete post; aluminum tablet stamped "1118"	1,117.554

Southeast corner of sec. 12, T. 126 N., R. 43 W., east along highway 1 mile, thence north to county line.

T. 126 N., R. 42 W., in northwest corner of SW. ¼ SW. ¼ sec. 8, 33 feet east of section line, in base of 5-inch tree; two spikes	1,148.79

CHOKIO QUADRANGLE.

Southwest corner of sec. 2, T. 126 N., R. 44 W., west to sec. 4, T. 126 N., R. 44 W.

T. 126 N., R. 44 W., in southwest corner of sec. 2, 35 feet east by 35 feet north of center of crossroads, 320 feet northeast of schoolhouse; iron post stamped "1080"	1,079.870
T. 126 N., R. 44 W., in southeast corner of sec. 4, 220 feet northwest of section corner, in base of cottonwood tree 8 inches in diameter; spike	1,076.48

Northeast corner of sec. 36, T. 125 N., R. 43 W., north along highway to southeast corner of sec. 12, T. 126 N., R. 43 W.

T. 125 N., R. 43 W., in northeast corner of sec. 36, 45 feet west by 30 feet south of 4-inch by 12-inch rock near corner, 60 feet north of center of road; iron post stamped "1110"	1,110.288
T. 125 N., R. 42 W., in northwest corner of sec. 18, 30 feet east by 65 feet south of center of crossroads, in top of concrete post; aluminum tablet stamped "1105"	1,104.981
Donnelly, 1 foot south of joint of east rails, on top of rail, main line opposite signal in front of station	1,129.1
Donnelly, at street crossing, 95 feet south of post office, west side of Main Street, at northeast entrance of park, in top of concrete post; aluminum tablet stamped "1131"	1,130.766
T. 126 N., R. 43 W., in southeast corner of sec. 12, 40 feet west by 20 feet north of center of crossroads, 210 feet west of church, in top of concrete post; aluminum tablet stamped "1144"	1,144.431

Southwest corner of sec. 19, T. 124 N., R. 42 W., west along highway 3 miles, thence north to Alberta.

T. 124 N., R. 43 W., in northwest corner of NE. ¼ NW ¼ sec. 25, 3 feet from trunk of tree and 35 feet west of center line of travel at jog around lake, in root of 32-inch tree; spike	1,144.26
T. 124 N., R. 43 W., in southwest corner of sec. 22, 25 feet north by 25 feet east of center of crossroads, in top of concrete post; aluminum tablet stamped "1149"	1,149.009
T. 124 N., R. 43 W., in northwest corner of sec. 10, 40 feet east by 30 feet south of center of road intersection, 0.25 mile west of Alberta, in top of concrete post; aluminum tablet stamped "1109"	1,108.810

Southwest corner of sec. 19, T. 124 N., R. 42 W., to northwest corner of sec. 4, T. 126 N., R. 44 W.

T. 124 N., R. 42 W., in southwest corner of sec. 19, 25 feet east by 35 feet north of center line of travel at crossroads; in top of concrete post; aluminum tablet stamped "1158"	1,157.450
T. 124 N., R. 43 W., northwest corner of NE. ¼ NW. ¼ sec. 25, 3 feet from trunk of tree and 35 feet west of center line of travel at jog around lake; nail in root of 32-inch tree	1,144.26

	Feet.
T. 124 N., R. 43 W., southwest corner of sec. 22, 25 feet north by 25 feet east of center line of travel at crossroads, in top of concrete post; aluminum tablet stamped "1149"	1,148.991
T. 124 N., R. 43 W., near northwest corner of sec. 32; iron post stamped "1156"	1,155.869
T. 124 N., R. 44 W., near southeast corner of sec. 25, nailhead in west end of small bridge painted white	1,152.60
T. 124 N., R. 44 W., southwest corner of sec. 26, in top of concrete post; aluminum tablet stamped "1157"	1,157.137
T. 124 N., R. 44 W., near southwest corner of sec. 29, in top of concrete post; aluminum tablet stamped "1163"	1,163.412
T. 124 N., R. 44 W., 200 feet northeast of southwest corner of sec. 20; chiseled square on top of large stone	1,158.48
T. 124 N., R. 44 W., near southeast corner of sec. 7; iron post stamped "1143"	1,142.967
T. 125 N., R. 44 W., near southwest corner of sec. 32; iron post stamped "1124"	1,124.229
T. 125 N., R. 44 W., near southeast corner of sec. 18; iron post stamped "1102"	1,102.148
T. 125 N., R. 44 W., northeast corner of sec. 6; iron post stamped "1073"	1,072.808
T. 126 N., R. 44 W., near northeast corner of sec. 19; iron post stamped "1064"	1,064.009
T. 126 N., R. 44 W., near northwest corner of sec. 4, 30 feet east by 25 feet south of center of crossroads; iron post stamped "1057"	1,057.267

Southwest corner of sec. 2, T. 126 N., R. 44 W., to southwest corner of sec. 22, T. 124 N., R. 43 W.

T. 126 N., R. 44 W., southwest corner of sec. 2, 35 feet east by 35 feet north of center line of travel at crossroads, 320 feet northeast of schoolhouse; iron post stamped "1080"	1,079.870
T. 126 N., R. 43 W., near northwest corner of sec. 7, in top of concrete post; aluminum tablet stamped "1089"	1,089.304
T. 126 N., R. 43 W., southwest corner of sec. 7; top of iron pipe	1,090.829
T. 126 N., R. 43 W., near northwest corner of sec. 20, in top of concrete post; aluminum tablet stamped "1089"	1,088.948
T. 126 N., R. 43 W., near northeast corner of sec. 32, in top of concrete post; aluminum tablet stamped "1110"	1,110.298
T. 125 N., R. 43 W., near southeast corner of sec. 8; iron post stamped "1122"	1,122.381
T. 125 N., R. 43 W., near corner of secs. 16, 17, 20, and 21; chiseled square on stone	1,124.59
T. 125 N., R. 43 W., 1,320 feet north of northwest corner of sec. 28; chiseled quare on large stone	1,123.32
T. 125 N., R. 43 W., near center of SE. ¼ sec. 32, in top of concrete post at tower; aluminum tablet stamped "1123"	1,122.726
T. 124 N., R. 43 W., in northwest corner of sec. 10, 30 feet south by 40 feet east of center line of travel at road intersection, 0.25 mile west of Alberta, in top of concrete post; aluminum tablet stamped "1109"	1,108.810

ASHBY QUADRANGLE.

Elbow Lake north along highways to Parkdale.

Elbow Lake, in north end of sandstone doorsill of First National Bank Building, 1.8 meters north of south side of building, 0.4 meter above sidewalk, 0.1 meter east of front edge of sill, 0.8 meter south of brickwork, 0.5 meter north of center of doorway; red metal disk (Coast and Geodetic Survey bench mark X-1)	1,213.903

	Feet.
T. 130 N., R. 42 W., northeast corner of sec. 31, 0.2 mile south of Woesner's house, 2 feet from fence line; iron post stamped "1179"	1,179.091
T. 130 N., R. 42 W., southeast corner of sec. 7, 0.5 mile west of Four-Mile Lake, 3 feet south of fence corner; iron post stamped "1177"	1,177.087
Ten-Mile Lake, 0.2 mile west of, 150 feet east of E. T. Reesburg's Lane, on south side of road, 2 feet north of fence line; iron post stamped "1236"	1,235.487
Ten-Mile Lake, water surface, July 21, 1910	1,198.5
T. 131 N., R. 42 W., near southeast corner of sec. 16, 0.2 mile east of north end of Ten-Mile Lake, 1,000 feet northwest of S. Foseen's house, 3 feet inside of fence and 4 feet on west side of road, on summit; iron post stamped "1229"	1,229.269
Parkdale Mill, 0.4 mile north of, southwest corner of sec. 33, T. 132 N., R. 42 W., 3 feet east of lane to Hans Rynn's house; iron post stamped "1259"	1,258.674
Parkdale, between fifteenth and sixteenth telegraph poles west of milepost 181, on public road, two-thirds meter south of right-of-way fence, in stone post lettered "U. S. B. M."; copper bolt (Coast and Geodetic Survey bench mark V-3)	1,233.511

Point 2 miles south of Swan Lake church north and east along highways to point 1.6 miles northeast of old Tordenskj post office, thence south along highways to point 1.5 miles northwest of Ashby.

Swan Lake Church, 75 feet northeast of, 6 miles southeast of Fergus Falls, 2 feet east of fence; iron post stamped "1313"	1,313.362
T. 132 N., R. 42 W., southeast corner of sec. 14, 700 feet southeast of P. Johnson's house, 30 feet west by 10 feet north of corner, near fence line; iron post stamped "1345"	1,344.912
Tordenskj post office (old), 0.9 mile northeast of, 120 feet north of mail box near forks of road to J. S. Torgenson's, 10 feet east of road; iron post stamped "1295"	1,295.020
T. 131 N., R. 41 W., east quarter corner of sec. 7, 2 miles east of Dalton, 100 feet northeast of Synod Church; iron post stamped "1358"	1,358.237
T. 131 N., R. 41 W., southeast corner of sec. 29, 3 miles northwest of Ashby, 60 feet northwest of A. L. Anderson's mail box, 3 feet east of fence; iron post stamped "1326"	1,326.246

Bench mark at southeast corner of sec. 29, T. 131 N., R. 41 W., south along highways to Thorsborg.

T. 130 N., R. 41 W., southwest corner of sec. 31, 4 miles northwest of Ashby, 2 feet west of fence; iron post stamped "1265"	1,264.891
T. 130 N., R. 42 W., northeast corner of sec. 24, at old Pomme de Terre post office, 400 feet south of crossroads, 3 feet east of fence; iron post stamped "1248"	1,247.831
T. 130 N., R. 42 W., northeast corner of sec. 35, 4 miles north of Thorsborg, corner of land owned by A. Woessner, 3 feet east of fence; iron post stamped "1199 Minn"	1,198.724
Thorsborg, in southeast quarter of sec. 13, 110 meters north by 60 meters west of station, at southwest corner of pasture belonging to Henry Lajord, at northeast corner of crossroads, 10 meters east by 5 meters north of line of travel; iron post (Coast and Geodetic Survey bench mark V-1)	1,204.971

Erdahl north along highways to Ashby.

Erdahl, on land of T. Tokiason, of Ashby, at east line of Main Street, 58 meters south of railway, at point 70 meters west of station, 7 meters east of line of travel, 17 meters northeast of frame store of A. J. Okelgren, 24 meters south of a grain elevator; iron post (Coast and Geodetic Survey bench mark U-1)	1,266.757

	Feet.
Erdahl, 3 miles north of, 250 feet west of K. E. Johnson's mail box, 30 feet north of road, inside of fence, near northeast corner of sec. 24, T. 130 N., R. 41 W.; iron post stamped "1225"	1,224.767
Pelican Lake; water surface, August 24, 1910	1,214.3
T. 130 N., R. 41 W., northeast corner of sec. 21, 2.5 miles south of Ashby, near telephone pole; iron post stamped "1250"	1,249.985
Ashby, at southwest corner of Melby and street one block south of Main Street, at northeast corner of property owned by J. Madland, 3 meters from property line; stone post lettered "U. S. B. M." (Coast and Geodetic Survey bench mark P-3)	1,295.682

Ashby north and west along highways to point near old Tordenskj post office.

Ashby, southwest corner of city park, northeast corner of Larson Street and street one block south of Main Street, 4 feet from sidewalk; iron post stamped "1295 Minn"	1,295.134
Ashby, 3 miles northeast of, at junction of road to Eagle Lake, 20 feet north of signpost reading "Eagle Lake 4 miles," at corner of Soren Knudson's land; iron post stamped "1281 Minn"	1,281.277
T. 131 N., R. 41 W., northwest corner of sec. 12, 6.8 miles northeast of Ashby, 30 feet north of circular mail box; iron post stamped "1318"	1,317.947
T. 132 N., R. 41 W., 0.2 mile west of southeast corner of sec. 25, 9.3 miles north of Ashby, 60 feet northeast of signpost reading "8 miles to Battle Lake," 20 feet east of road; tack in stump painted "U. S. B. M. 1356.6"	1,356.57
T. 132 N., R. 41 W., 0.5 mile east of northwest corner of sec. 25, 10.4 miles northeast of Ashby, 60 feet east of signpost at forks of road reading "Battle Lake 7 miles, Fergus Falls 17 miles," east side of north-south road; iron post stamped "1381"	1,380.745
T. 132 N., R. 41 W., 0.2 mile west of center of sec. 27, 800 feet southeast of G. Krilvang's house, 12.9 miles north of Ashby, 20 feet north of road; iron post stamped "1282 Minn"	1,282.108

WENDELL QUADRANGLE.

Point 1.2 miles south of Wendell along highways to north quarter corner of sec. T. 132 N., R. 43 W.

T. 130 N., R. 43 W., northeast corner of sec. 34, 25 feet south by 25 feet west of center of line of travel at crossroads; iron post stamped "1118"	1,118.102
T. 130 N., R. 43 W., northwest corner of sec. 14, 25 feet south by 25 feet east of center of line of travel at crossroads; iron post stamped "1148"	1,147.576
T. 131 N., R. 43 W., northeast corner of sec. 34, 30 feet south by 20 feet west of center of line of travel at crossroads; iron post stamped "1146"	1,146.114
T. 131 N., R. 43 W., northwest corner of sec. 14, 15 feet east by 30 feet south of center of line of travel at crossroads; iron post stamped "1192"	1,192.230
T. 132 N., R. 43 W., 0.2 mile north of southeast corner of sec. 35, 15 feet north of road, near fence line; iron post stamped "1256"	1,256.161
T. 132 N., R. 43 W., north quarter corner of sec. 32, 60 feet northwest of C. A. Littson's, 150 feet southwest of schoolhouse at T road north; iron post stamped "1171"	1,170.845

Point 2.1 miles south of Fergus Falls to point one-fourth mile south of northeast corner of sec. 27, T. 132 N., R. 43 W.

Fergus Falls, 3.8 miles southeast of, 100 feet east of slough, 50 feet east of road northwest corner of pasture owned by C. M. Anderson; iron post stamped "1170 Minn"	1,169.687

FERGUS FALLS QUADRANGLE.

Fergus Falls south along highways 2.5 miles.

	Feet.
Fergus Falls, at southeast corner of Lincoln Avenue and Mill Street, on doorstep of northern entrance of the Pickett Block (First State Bank Building), in middle of building, 10 centimeters from north edge, and 15 centimeters from east edge of step; chiseled square (Coast and Geodetic Survey bench mark Y-3)	1, 195. 991

Fergus Falls north along highways to Erharts, thence east along highways to southeast corner of sec. 25, T. 135 N., R. 44 W.

Fergus Falls, 3.7 miles northeast of, near southeast corner of sec. 24, T. 133 N., R. 43 W., 30 feet south by 30 feet west of forks in road, 150 feet west of schoolhouse (district No. 80); iron post stamped "1313 Minn"	1, 312. 578
T. 133 N., R. 42 W., northwest corner of sec. 7, 150 feet northwest of H. Holdhusen's house, 20 feet east of road; iron post stamped "1300 Minn"	1, 299. 930
T. 134 N., R. 43 W., southeast corner of sec. 23, 55 feet north by 10 feet west of crossroads, at edge of C. F. Ladwig's farm; iron post stamped "1354 Minn"	1, 353. 786
T. 134 N., R. 43 W., southwest corner of sec. 23, 20 feet north of W. B. Chapin's mail box; spike in silver poplar tree marked "1317.6"	1. 317. 61
T. 134 N., R. 43 W., southwest corner of sec. 14, 35 feet northeast of B. Langer's mail box; iron post stamped "1345 Minn"	1, 344. 925
T. 134 N., R. 43 W., 800 feet west of northwest corner of sec. 14; 5 feet north of road; spike in stump marked "1287.8"	1, 287. 81
T. 134 N., R. 43 W., 0.25 mile south of northwest corner sec. 11, at foot of T. Svensgaard's mail box; iron stake marked "1336.5"	1, 336. 48
T. 134 N., R. 43 W., north quarter corner of sec. 11, 60 feet southwest of schoolhouse, 20 feet east of road; iron post stamped "1361 Minn"	1, 361. 305
T. 135 N., R. 43 W., northeast corner of sec. 34, 10 feet south of P. Ganen's mail box; iron post stamped "1431 Minn"	1, 431. 130
Erharts, on southwest corner of cement walk leading to A. O Solom's house on Main street; chiseled square	1, 293. 23
T. 135 N., R. 43 W., southwest corner of sec. 21, 1 mile west of Erharts, 200 feet north of schoolhouse (district No. 36); iron post stamped "1322 Minn."	1, 322. 067
T. 135 N., R. 44 W., southwest corner of sec. 25, 30 feet north of road near slough; iron post stamped "1281 Minn."	1, 280. 767

Southeast corner of sec. 25, T. 135 N., R. 44 W., south along highways to Fergus Falls.

T. 134 N., R. 43 W., 1,600 feet southeast of southwest corner of sec. 6, 15 feet north by 30 feet west of forks in road, at edge of O. Zimmerman's farm; iron post stamped "1338 Minn."	1, 337. 933
T. 134 N., R. 44 W., southeast corner of sec. 24, 175 feet north by 20 feet west of forks in road; iron post stamped "1338 Minn."	1, 338. 367
T. 133 N., R. 43 W., northwest corner of sec. 5, 30 feet north by 25 feet east of forks in road; iron post stamped "1308"	1, 308. 250
Fergus Falls, 5 miles northwest of, on northeast corner of bridge over Pelican River; bolt marked "1193.5"	1, 193. 38
T. 134 N., R. 43 W., southeast corner of sec. 31, 20 feet north by 30 feet west of crossroads; iron post stamped "1231"	1, 230. 824

Fergus Falls east 2.5 miles along Great Northern Railway.

Fergus Falls, south of track on southeast foundation of Great Northern Railway water tank in southeast corner of stone; the bottom of a hole in a horizontal surface 25 millimeters square and 4 millimeters deep (Coast and Geodetic Survey bench mark)	1, 195. 684

	Feet.
Fergus Falls, 2.5 miles east of, 9 feet north of railroad, 720 feet west of Electric Power Co.'s dam across Ottertail River; highest point of granite rock	1, 126. 29

Northeast corner of sec. 32, T 135 N., R. 42 W., to north line of sec. 11, T. 134 N., R. 43 W.

T. 135 N., R. 42 W., 60 feet west by 25 feet south of northeast corner of sec. 32; highest point on granite rock	1, 469. 95
T. 135 N., R. 42 W. 20 feet north by 25 feet east of southwest corner of sec. 32; iron post stamped "1449"	1, 448. 641
T. 135 N., R. 43 W., southeast corner of sec. 36, 60 feet west by 25 feet north of; chiseled square on granite rock	1, 483. 82
T. 134 N., R. 43 W., north quarter corner of sec. 11, 60 feet southwest of schoolhouse, 20 feet east to public road; iron post stamped "1361 Minn.".	1, 361. 305

Point near southwest corner of sec. 3, T. 132 N., R. 44 W., to point near southwest corner of sec. 8, T. 134 N., R. 44 W.

French, T. 133 N., R. 44 W., 60 feet west of station, 60 feet north of Northern Pacific Railway; iron post stamped "1111"	1, 111. 260
T. 133 N., R. 44 W., 30 feet west of southeast corner of sec. 16; iron post stamped "1191"	1, 191. 164
T. 133 N., R. 44 W., 15 feet south of northwest corner of sec. 16; highest point on granite rock	1, 144. 19
T. 133 N., R. 44 W., 30 feet south by 30 feet east of northwest corner of sec. 8; iron post stamped "1124"	1, 124. 304
T. 134 N., R. 44 W., 20 feet south of northwest corner of sec. 31; top of granite rock	1, 152. 16
T. 134 N., R. 44 W., 45 feet west by 25 feet south of northeast corner of sec. 30; iron post stamped "1161"	1, 160. 869

BATTLE LAKE QUADRANGLE.

Point 5.2 miles east of Underwood east along Great Northern Railway to Battle Lake, thence north along highways to southwest corner of sec. 16, T. 134 N., R. 40 W.

Underwood, 5.2 miles east of, 25 feet south of railroad, 50 feet east of wagon road, at private crossing; highest point on granite rock	1, 339. 84
Battle Lake, southeast corner of yard of new schoolhouse; iron post stamped "1373 Prim. Trav. Sta. No. 13" (on unchecked spur line)	1, 373. 256
T. 133 N., R. 40 W., 20 feet east by 25 feet north of southwest corner of SE. ¼ sec. 20, 3.2 miles northwest of Battle Lake; iron post stamped "1338"	1, 388. 196
T. 133 N., R. 40 W., near southeast corner of NW. ¼ sec. 9; iron post stamped "Prim. Trav. Sta. No. 15, 1363"	1, 362. 603
T. 133 N., R. 40 W.; north of first bolt head on northeast corner of bridge over Red River at outlet of Ottertail Lake	1, 327. 08
Red River; surface of water under bridge, Nov. 1, 1910	1, 319. 2
T. 134 N., R. 40 W., at T road west, on west end of Ottertail Lake; iron post stamped "Prim. Trav. Sta. No. 16, 1330"	1, 330. 418
T. 134 N., R. 40 W., near southwest corner of sec. 16, in southwest corner of church lot; iron post stamped "Prim. Trav. Sta. No. 17, 1368" (on unchecked spur line)	1, 368. 330

ROTHSAY QUADRANGLE.

Northeast corner of sec. 32, T 135 N., R. 44 W., to Rothsay.

T. 135 N., R. 44 W., 0.2 mile west of northeast corner of sec. 32, 30 feet south of road; iron post stamped "1279 Minn."	1, 279. 252
Rothsay, on cement step of east door on north side of brick creamery; chiseled point	1, 198. 47

	Feet.
Rothsay, First State Bank Building corner Second and Main Streets; chiseled hole in step on south side (Coast and Geodetic Survey bench mark)	1, 201. 632

Northwest corner of sec. 8, T. 134 N., R. 44 W., north to Rothsay.

T. 134 N., R. 44 W., 40 feet south by 25 feet west of northwest corner of sec. 8; iron post stamped "1188"	1, 188. 584

UNDERWOOD QUADRANGLE.

Point 3.3 miles east of Fergus Falls along Great Northern Railway to Underwood, thence north along highways to point near corner of sec. 30, T. 135 N., R. 42 W.

Wall Lake, 0.6 mile west of, 40 feet south of railroad, in northwest corner of railroad right-of-way, at railroad crossing; iron post stamped "1257"	1, 256. 877
Wall Lake, in front of station; top of rail	1, 288. 4
Underwood, 3.2 miles west of, 50 feet north of railroad, in southeast corner of T road; iron post stamped "1339"	1, 339. 015
Underwood, 40 feet west of station, 20 feet south of railroad track, in small grass park; iron post stamped "1343"	1, 342. 640
Underwood, 1 mile north of, at T road east, west side of road; paint spot on highest point on large rock	1, 361. 00
T. 133 N., R. 41 W., near center of sec. 20, 75 feet northwest of schoolhouse No. 109, in southeast corner of C. A. Weaver's farm; iron post stamped "1347"	1, 347. 259
Underwood, 3.5 miles north of, on concrete foundation of guide post marked "Fergus Falls 12 miles, Underwood 3.5 miles, Phelps 6 miles"; chiseled square	1, 341. 22
Underwood, 5.6 miles north of, northwest corner of bridge over ditch that connects Lake Anna with Little Lake Anna; nailhead	1, 325. 66
T. 133 N., R. 41 W., near southwest corner of sec. 4, on east side of road; iron post stamped "1345"	1, 344. 867
T. 133 N., R. 41 W., near northwest corner of sec. 4, 150 feet northwest of schoolhouse; iron bolt in root of elm tree	1, 379. 55
T. 134 N., R. 41 W., in sec. 31, on east side of road, at Y road between Lost Lake and Little Lost Lake; iron post stamped "1321"	1, 321. 006
Wegland post office, 0.6 mile south of, on west side of road opposite lake; chiseled square on granite rock	1, 339. 50
Wegland, in front of post office; ground elevation	1, 350. 8
Wegland, 0.4 mile northeast of, in sec. 26, T. 134 N., R. 42 W., 60 feet north of north end of Wegland bridge over Ottertail River, in forks of road; iron post stamped "1313 Minn."	1, 312. 620
T. 134 N., R. 42 W., 22 feet northeast of southwest corner of sec. 14; chiseled square on large granite rock	1, 332. 01
T. 134 N., R. 42 W., in south part of sec. 14, 17 feet south of road at Y road; chiseled square on top of large granite rock	1, 397. 57
T. 134 N., R. 42 W., 2 feet south of northeast corner of SE. ¼ sec. 14; iron post stamped "1372"	1, 371. 724
T. 135 N., R. 41 W., 555 feet north of southwest corner of SE. ¼ sec. 31; iron post stamped "1363 Minn."	1, 362. 697
T. 135 N., R. 41 W., near southwest corner of NW. ¼ sec. 30, in northwest corner of crossroads; chiseled square on granite rock	1, 403. 10
T. 135 N., R. 42 W., 30 feet south of northeast corner of sec. 26; iron post stamped "1415"	1, 414. 842
T. 135 N., R. 42 W., 20 feet south by 30 feet west of northeast corner of sec. 27, 270 feet west of schoolhouse; chiseled square on rock	1, 459. 55
T. 135 N., R. 42 W., near southeast corner of sec. 20, 30 feet north by 30 feet east of center of crossroads; iron post stamped "1439"	1, 438. 644

Underwood east along Great Northern Railway 3.57 miles.

	Feet.
Underwood, 2 miles east of, 25 feet south of railroad, 20 feet west of wagon road at railroad crossing; highest point on granite rock	1,344.77
Underwood, 3.6 miles east of, 45 feet south of railroad, on right of way, 15 feet east of T road north; iron post stamped "1342"	1,341.573

Point near northwest corner of sec. 20, T. 134 N., R. 40 W., east along highways to southwest corner of NW. ¼ sec. 30, T. 135 N., R. 41 W.

T. 134 N., R. 41 W., 330 feet west of southeast corner of sec. 1, on east side of road; iron post stamped "1332"	1,331.534
T. 134 N., R. 41 W., 16.5 feet south by 650 feet east of northwest corner of sec. 3; iron post stamped "1337" (in forks of road)	1,338.284
T. 135 N., R. 41 W., northwest corner of T road north, at Star Lake; spike in root of elm tree	1,334.16
Bridge at west end of Dead Lake	1,332.8
T. 135 N., R. 41 W., near northeast corner of SW. ¼ sec. 28, 1.2 miles north of Star Lake; spike in root of oak tree	1,354.10
T. 135 N., R. 41 W., near northeast corner of sec. 29; iron post stamped "Prim. Trav. Sta. No. 20 1375"	1,375.835
T. 135 N., R. 41 W., near southwest corner of NW. ¼ sec. 30, in northwest corner of crossroads; chiseled square on granite rock	1,403.103

Anoka and White Bear Quadrangles.

ANOKA, HENNEPIN, AND RAMSEY COUNTIES.

The elevations in the following list are based on various bench marks of the Mississippi River Commission in this locality. The elevation of the bench mark in the west end of doorsill at south entrance to basement of courthouse at St. Paul, Minn., which is a copper bolt marked "U. S. P. B. M. 72," is taken as 780.555 feet above mean sea level.

The leveling was done in 1899 by D. C. Wray.

WHITE BEAR QUADRANGLE.

St. Paul north along Rice Street, thence east along roads to White Bear, thence south to St. Paul.

	Feet.
T. 29 N., R. 22 W., northwest corner of sec. 6; iron post stamped "St. P. 924"	925.422
White Bear, in northwest corner of Catholic Church yard; iron post stamped "932 St. P."	934.106

White Bear north along highway to center of T. 32 N., R. 22 W., thence southwest to Minneapolis.

Centerville, at southeast corner of cemetery; iron post stamped "909 St. P."	910.646
T. 32 N., R. 22 W., sec. 28, at southeast corner of schoolhouse yard (district No. 9), east side of road; iron post stamped "909 St. P."	910.542
T. 31 N., R. 23 W., crossroads, 0.25 mile north of southeast corner of sec. 26· iron post stamped "910 St. P."	911.741
T. 30 N., R. 23 W., in southeast corner of sec. 17, 1.5 miles north of New Brighton, at junction of road to east with north and south road; iron post stamped "913 St. P."	914.359

Findley east to and north along Central Avenue to T. 32 N., R. 23 W., sec. 20.

	Feet.
T. 32 N., R. 23 W., center of sec. 20, at forks of Central Avenue and Anoka roads; iron post stamped "905 St. P."	906.321

ANOKA QUADRANGLE.

Bench mark east of Findley.

T. 30 N., R. 24 W., 0.2 mile west of center of sec. 14; east corner of school yard; iron post stamped "858 St. P."	859.425

T. 32 N., R. 23 W., west and thence south to Powell.

T. 32 N., R. 24 W., near center of sec. 26; on west line of schoolhouse yard, 50 feet north of east and west road; iron post stamped "891 St. P."	892.617
T. 31 N., R. 24 W., quarter corner north side of sec. 16, at southwest corner of crossroads; iron post stamped "869 St. P."	870.811

Anoka north 4 miles, thence southwest to river.

T. 32 N., R. 25 W., northwest corner of sec. 26, 50 feet east of crossroads; iron post stamped "892 St. P."	893.961

Anoka west along highway to Dayton, thence south to Rockford Road, thence east to Robinsdale, thence north to Anoka.

T. 120 N., R. 22 W., southeast quarter of sec. 17, in southwest corner of town hall of Dayton township; iron post stamped "912 St. P."	913.705
T. 119 N., R. 22 W., sec. 27, near center of, in southeast corner of schoolhouse yard, northwest corner of crossroads; iron post stamped "942 St. P."	944.172
T. 118 N., R. 22 W., on north and south quarter line of sec. 14, at northeast corner of German Lutheran churchyard, 300 feet north of Rockford Road; iron post stamped "943 St. P."	944.695
Robinsdale, on south line of Village Hall; iron post stamped "879 St. P."	880.927
T. 119 N., R. 21 W., sec. 21, 0.25 mile east of southwest corner of, in northwest corner of yard of Brooklyn town hall; iron post stamped "879 St. P."	880.148
T. 120 N., R. 21 W., quarter corner south side of sec. 30, northwest corner of school yard, east side of Champlain and Anoka Roads; iron post stamped "883 St. P."	884.750

Minnetonka and Norwood Quadrangles.

CARVER AND HENNEPIN COUNTIES.

The elevations in the following list are based on bench marks of the Mississippi River Commission through leveling on the Anoka quadrangle.

The leveling was done in 1905 by H. Bucher.

The standard bench marks are stamped "ADJ 1903" in addition to the figures of elevation.

MINNETONKA QUADRANGLE.

German Lutheran Church in sec. 14, T. 118 N., R. 22 W., southwest to point about 1 mile east of town of Wayzata and return.

	Feet.
T. 118 N., R. 22 W., 0.2 mile north of southeast corner of sec. 30, at southwest corner of crossroads, between two mail box posts; iron post stamped "ADJ 1903 996"	996.353

Wayzata west along railroad and highway to sec. 34, T. 118 N., R. 24 W.; thence southwest to St. Bonifacius.

	Feet.
Ferndale station, Great Northern Railway, 50 feet east of station; top of rail	984.7
Long Lake station, at crossing; top of rail	989.1
Long Lake station, on east side of wagon road 20 feet north of track, 5 feet west of large telegraph pole; iron post stamped "ADJ 1903 989"	988.877
T. 118 N., R. 23 W., northwest corner of sec. 32, 0.2 mile from crossroads on north side of Great Northern Railway, at northeast corner, 28 feet east of fence corner, 1 foot south of fence; iron post stamped "ADJ 1903 997"	996.889
T. 118 N., R. 24 W., 0.1 mile east of northwest corner of sec. 35, at northwest corner of lawn of house of F. O. Johnson, in large white bowlder on south side of road; aluminum tablet stamped "ADJ 1903 1024"	1,023.974
T. 117 N., R. 24 W., 0.3 mile north of southwest corner of sec. 3, on north side of road at northeast corner of crossroads, 10 feet west of large elm; iron post stamped "ADJ 1903 968"	968.507
T. 117 N., R. 24 W., northwest corner of sec. 17, at southwest corner of crossroads, 5 feet from fence corner; iron post stamped "ADJ 1903 967"	966.925
T. 117 N., R. 24 W., 0.3 mile north of southwest corner of sec. 32, 0.6 mile south of St. Bonifacius, on east side of road at southwest corner of Thos. Kohlman's yard, primary traverse post, No. 7; iron post stamped "ADJ 1903 960"	959.895

St. Bonifacius east along highway and railroad to Excelsior, thence north to Wayzata.

T. 116 N., R. 24 W., northwest corner of sec. 3, at southeast corner of road intersection, 10 feet south of guide post at corner; iron post stamped "ADJ 1903 1005"	1,004.968
T. 116 N., R. 24 W., 0.3 mile north by 0.1 mile west of southeast corner of sec. 1, at southeast corner of schoolhouse, on north side of road, at intersection; iron post stamped "ADJ 1903 1020"	1,019.855
Eureka station, 400 feet northeast of, in lower upright stone of stone culvert under fill, at west corner; aluminum tablet stamped "ADJ 1903 957"	956.957
Excelsior schoolhouse, in top row of masonry of west wall, 4 feet north of southwest corner of building; aluminum tablet stamped "ADJ 1903 973".	973.295
T. 117 N., R. 23 W., 0.1 mile north of southeast corner of sec. 24, in northeast corner of Deephaven schoolhouse grounds, south of north fence and 3 feet west of northeast corner; iron post stamped "ADJ 1903 984"	984.512
Northome, road crossing; top of rail	939.8
Breezy Point, road crossing; top of rail	954.2
T. 117 N., R. 22 W., 0.1 mile south of northeast corner of sec. 18, on west side of road, 22 feet north of track of Chicago, Milwaukee & St. Paul Railway, 22 feet east of cattle-guard fence and 9 feet northwest of crossing post; iron post stamped "ADJ 1903 964"	964.542

Excelsior south along highway to Shakopee, thence west along railroad, thence north to St. Bonifacius.

T. 116 N., R. 23 W., 300 feet south of northeast corner of sec. 1, on west side of road, primary traverse point No. 3; iron post stamped "Prim. Trav. Sta. No. 3, ADJ 1903 957"	957.708
Chanhassen, in masonry abutment wall around St. Ruperts Church, 17 feet south of end of wall at church step, 6 feet north of gateway to garden; aluminum tablet stamped "ADJ 1903 976"	976.093

	Feet.
T. 116 N., R. 23 W., 0.1 mile north by 0.1 mile east of west quarter corner of sec. 36, 15 feet north of Minneapolis & St. Louis Railroad, 100 feet west of railroad bridge over wagon road, primary traverse No. 4; iron post stamped "ADJ 1903 815"	815.650
Shakopee, at courthouse, in masonry foundation of east wing of, 14 feet south of northeast corner of wing; aluminum tablet stamped "ADJ 1903 792"	792.211
Chaska, 40 feet west of station, 15 feet north of track of Minneapolis & St. Louis Railroad, "Prim. Trav. Sta. No. 5;" iron post stamped "ADJ 1903 728"	728.781
T. 115 N., R. 23 W., in SE. ¼ sec. 18, Carver station, Chicago, Milwaukee & St. Paul Railroad, on west side of public road, 20 feet south of main track, 4.5 feet south of crossing; iron post stamped "ADJ 1903 815"	815.435
T. 115 N., R. 24 W., 0.1 mile south of northeast corner of sec. 15, on east side of public road, 34 feet south of Chicago, Milwaukee & St. Paul track, 18 feet west of fence; iron post stamped "ADJ 1903 981"	981.335
T. 115 N., R. 24 W., southwest corner of sec. 9, at northeast corner of crossroads, 3 feet north of and 1.5 feet west of fence; iron post stamped "ADJ 1903 933"	933.378
T. 116 N., R. 24 W., 0.2 mile west of southeast corner of sec. 34, railroad crossing at Augusta Station, Chicago, Milwaukee & St. Paul Railroad, at southeast corner of, 1 foot northwest of fence and 11 feet southwest of fence corner; iron post stamped "ADJ 1903 982"	982.726
T. 116 N., R. 24 W., 0.1 mile north of south quarter corner of sec. 21, on east side of road, 34 feet south of private road (to west), to house of F. J. Poppler, 1 foot west of fence and 14 feet north of 30-inch cottonwood tree; iron post stamped "ADJ 1903 1019"	1,019.294

NORWOOD QUADRANGLE.

T. 116 N., R. 24 W., 0.1 mile west of north quarter corner of sec. 18, at southwest corner of grounds of Swedish Baptist Church, at northeast corner of road intersection, on line of fence, on east side of road; iron post stamped "ADJ 1903 1012"	1,011.873

Elk River and Rockford Quadrangles.

HENNEPIN AND WRIGHT COUNTIES.

The elevations in the following list are based on the precise leveling of the Mississippi River Commission through leveling on Minneapolis and Lake Minnetonka quadrangles; no connection was made at Dayton.

The leveling was done in 1907 by E. M. Bandli.

ROCKFORD QUADRANGLE.

Point near Maple Plain northwest along highway and north to schoolhouse at northeast corner of sec. 15, T. 119 N., R. 24 W., thence east to sec. 25, T. 119 N., R. 23 W., thence south to sec. 30, T. 118 N., R. 23 W.

	Feet.
T. 118 N., R. 23 W., sec. 32, in northwest corner of, 0.2 mile from crossroads on north side of Great Northern Railway at northeast corner, 28 feet east of fence corner, 1 foot south of fence; iron post stamped "997 ADJ 1903"	996.885
Maple Plain, T. 118 N., R. 24 W., near center of sec. 25, railroad crossing just west of station, top of north rail	1,013.3

	Feet.
Armstrong, T. 118 N., R. 24 W., near west center of sec. 23, at road crossing; top of south rail of Great Northern Railroad	986.4
T. 118 N., R. 24 W., sec. 4, south center of, 1 foot west of fence corner at southeast corner of crossroads; iron post stamped "1034"	1,034.347
T. 119 N., R. 24 W., sec. 28, east center of, northwest corner of crossroads, 1 foot east of southeast corner of schoolhouse; iron post stamped "1035".	1,035.221
T. 119 N., R. 24 W., sec. 15, near northeast corner of, southwest corner of crossroads, 1 foot from northeast corner of schoolhouse; iron post stamped "996"	996.592
T. 119 N., R. 23 W., sec. 18, near north center of, Buschville, 90 feet west of southwest corner of crossroads at corner of lane fence; iron post stamped "1011"	1,012.091
Corcoran, Town Hall, T. 119 N., R. 23 W., sec. 16, near east center of, in southeast corner of crossroads, 1 foot north by 1 foot east of; iron post stamped "1027"	1,028.927
T. 119 N., R. 23 W., east center of sec. 25, southeast corner of T road, 1 foot from fence, 6.5 feet south of corner; iron post stamped "979"	979.715
Hamel, T. 118 N., R. 23 W., sec. 12, near southeast corner of; 50 feet north of "Soo" track and a few rods from station; iron post stamped "986"	986.402
T. 118 N., R. 22 W., sec. 30, near east center of, northwest corner of T road intersection; iron post stamped "Prim. Trav. Sta. No. 2, 1904, C. R. 998"	1,002.344

Sec. 15, T. 119 N., R. 24 W., northwest and north to sec. 33, T. 121 N., R. 24 W., thence east to schoolhouse in sec. 31, T. 121 N., R. 23 W.

T. 120 N. R. 24 W., sec 4, northeast corner of, in southeast corner of road intersection, 2 feet north from southeast corner fence post; iron post stamped "996"	996.323
T. 120 N., R. 24 W., sec. 29, north center of, 10 feet east by 4 feet north of crossroads near northeast corner fence post, in northeast corner of T road intersection; iron post stamped "998"	997.798
T. 120 N., R. 24 W., sec. 9, near west center of, in northeast corner of T road intersection, 5 feet south of southeast corner of schoolhouse, 1.5 feet east of southeast corner of hall; iron post stamped "963"	963.586
T. 121 N., R. 24 W., sec. 33, center of, opposite T road intersection; iron post stamped "Prim. Trav. Sta. No. 10 974"	974.631
T. 121 N., R. 24 W., sec. 35, near southeast corner of, at road crossing, in northwest corner of, 8 feet north of northwest corner fence post and 2 feet east of fence in Great Northern Railroad right of way; iron post stamped "961"	960.784
T. 121 N., R. 23 W., sec. 31, in northeast quarter of south side of schoolhouse 3 feet east by 1 foot north of southeast corner of projecting entrance of hall; iron post stamped "950"	958.690

Dayton south along highway to sec. 25, T. 119 N., R. 23 W.

Dayton, west of, T. 121 N., R. 23 W., east center of sec. 36, at northeast corner of bridge across Crow River, 6 feet west of lamp post; aluminum tablet stamped "864"	864.627
T. 120 N., R. 23 W., sec. 30, southwest corner of, 3 feet north of telegraph pole, east of T road, south of Great Northern Railroad; iron post stamped "958".	959.017
T. 119 N., R. 23 W., sec. 12, east center of, 3 feet northwest of southwest corner fence post, in southwest corner of crossroads; iron post stamped "939"	938.911

ELK RIVER QUADRANGLE.

Sec. 31, T. 121 N., R. 23 W., east to Dayton.

	Feet.
T. 121 N., R. 23 W., sec. 26, southwest corner of, 2 feet west of northeast corner fence post, at T road intersection; iron post stamped "880"	880. 307

Center City and St. Croix Dalles Quadrangles.

CHISAGO COUNTY.

The elevations in the following list are based upon P. B. M. 29A of the precise leveling of the United States Engineer Corps at the village of Wyoming, the elevation of which is 892.119 feet above mean sea level. From this point a double rodded line of primary levels was run to Taylors Falls, the remainder of the work being based thereon. The bench marks in Wisconsin upon St. Croix Dalles quadrangle are given in another list.

The leveling was done in 1897 by S. P. Connor.

CENTER CITY QUADRANGLE.

Chisago City east along Northern Pacific Railway to Center City.

	Feet.
Chisago City, in southeast corner of station platform; copper nail	922. 92
Center City, in southwest corner of station platform; copper nail	907. 93

ST. CROIX DALLES QUADRANGLE.

Center City east along Northern Pacific Railway to Taylors Falls.

Shafer, in front of station; top of rail	941. 7
T. 34 N., R. 19 W., sec. 32, southwest quarter of, 100 feet west of railroad station at Shafer; iron post stamped "T F 941"	942. 968
Franconia, in front of station; top of rail	910. 8
Taylors Falls, opposite east door of station; top of platform	800. 00
Taylors Falls, in front of station; top of rail	796. 2
Taylors Falls, Hotel Cocheco, front wall, northwest corner of; bronze tablet stamped "T F 757"	758. 720
Taylors Falls, brick schoolhouse 100 feet north of; bronze tablet in trap rock stamped "T F 890"	892. 035
Taylors Falls, 100 feet south of Taylors Falls bridge tollhouse, in top of stone; bronze tablet stamped "T F 713"	714. 960
Taylors Falls, at boat landing, in flat trap rock; bronze tablet stamped "T F 703"	704. 817
Taylors Falls, southwest corner of street north of Inter-State Park office, in stone; bronze tablet stamped "T F 743"	744. 735
T. 35 N., R. 19 W., sec. 34, in east half of, in front of Daubney's house; iron post stamped "T F 773"	774. 657

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 454

COAL, OIL, AND GAS
OF THE
FOXBURG QUADRANGLE, PENNSYLVANIA

BY

EUGENE WESLEY SHAW
AND
MALCOLM J. MUNN

WASHINGTON
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COAL, OIL, AND GAS OF THE FOXBURG QUADRANGLE, PENNSYLVANIA.

By EUGENE WESLEY SHAW and MALCOLM J. MUNN.

INTRODUCTION.

The area discussed in this bulletin is a 15-minute quadrangle of the United States Geological Survey, bounded by meridians 79° 30′ and 79° 45′ and parallels 41° 00′ and 41° 15′. These inclose a rectangle about 13 miles wide from east to west and about 17 miles long from north to south, containing about 225 square miles. The area is in the central part of western Pennsylvania, about 75 miles north of Pittsburg (see Pl. I, in pocket), and embraces parts of Venango, Clarion, Armstrong, and Butler counties. Foxburg, from which the quadrangle is named, stands about 3 miles west of the center of the quadrangle. The other principal towns are Emlenton, Knox, St. Petersburg, Callensburg, Parkers Landing, West Monterey, Rimersburg, Petrolia, and Fairview. A description of the triangulation work upon which the topographic map of the quadrangle is based will be found in United States Geological Survey Bulletin 181.

The Foxburg quadrangle lies in the great coal, oil, and gas producing region of western Pennsylvania. It contains many beds of coal, all of which outcrop extensively and none of which lie under more than a few hundred feet of cover. The oil and the gas are found in wells that range in depth from 600 to 2,500 feet, the deeper wells reaching the lower oil and gas-bearing strata and the shallower ones stopping in the upper sands. The oil and gas-bearing strata, like the coal beds, are nearly horizontal, though in general the former appear to have slightly greater dips.

Although the quadrangle has yielded millions of dollars worth of coal, oil, and gas, its fuel resources are not half exhausted, and it also contains valuable deposits of clay, sand, gravel, limestone, shale, sandstone, and iron ore. The other mineral resources are not so important as the coal, oil, and gas, and, as they are described in the Foxburg-Clarion folio of the Geologic Atlas (folio 178), they will not be considered in the present report. Much of the coal mined is used in the quadrangle, but all of it is within easy reach of lines of transportation, and the part which is shipped finds a ready market in the great noncoal-bearing area to the north, including northwestern Pennsylvania, New York, Ontario, and Quebec. The oil passes from the wells into pipe lines and is pumped to refineries, some of them near by and some at long distances. The gas flows into pipe lines also and is mixed with gas from other districts; some of it is consumed locally and practically all is burned in western Pennsylvania.

The region has been studied and described by several geologists, the most important reports being those of the Second Geological Survey of Pennsylvania, particularly Report VV, on Clarion County, by H. M. Chance, and Report III, on the oil regions, by John F. Carll.

In undertaking the present geological survey, the field work of which was done in 1908, it was considered unnecessary to duplicate the work of former surveys, except so far as to test by modern methods the results previously obtained. The aim of the present survey, therefore, was to devote especial attention to the features which received least attention in previous reports. Under this general plan the geologic structure, or lay of the beds, and the detailed distribution of various kinds of rocks have been carefully studied in the field and, so far as practicable, recorded on the maps. The geology of the coals is described by Mr. Shaw, the geology of the oil and gas by Mr. Munn.

TOPOGRAPHY AND DRAINAGE.

This quadrangle lies wholly within the basin of Allegheny River, which receives Clarion River from the east as its principal tributary in this area. These rivers have in comparatively recent time cut deep, narrow, gorge-like valleys across what was once a fairly level surface, and during the course of this downward cutting the smaller streams tributary to them have also deepened their valleys in a similar manner. Near the mouths of these smaller streams their valley walls are precipitous. Toward their sources, the hills rise less abruptly into flat or well-rounded summits. The difference in altitude of hills and adjacent valleys ranges from less than 200 to about 700 feet, the variation bearing a close relationship to the size of the streams. The lowest point in the area is about 815 feet above mean sea level and the highest is about 1,650, but the relief of every square mile amounts to several hundred feet. Thus the general elevation does not vary greatly and the hills are roughly concordant in height.

The brown lines on the map (Pl. I) are surface contours, indicating elevations above sea level and the shapes and sizes of the hills and valleys. Each contour passes through points of equal elevation. For example, the line bearing the figures 1,200 passes through points 1,200 feet above sea, the next higher passes through points 1,220 feet above sea, and so on. Thus almost the exact elevation of any point above sea level may be determined by locating the point on the map and noting its position with reference to the contours.

Perhaps the most striking topographic features are the canyon-like gorges of the rivers. Two miles southeast of Emlenton the Allegheny Valley is scarcely a mile wide, but is 660 feet deep. Flood plains are very narrow or absent, and the farming is on the upland, where there is much gently undulating country. The rivers are crooked and have some very long curves where the stream doubles back upon itself, but the valley is no shorter, because the walls follow the stream around its meanders. The entrenching of these streams is probably due in large part to Pleistocene or perhaps Pliocene uplift of the region, and in a lesser degree to increased volume of the Allegheny since the enlargement of its basin.

The contours of the hills depend, to some extent, upon the rocks of which they are composed. In areas where heavy sandstone predominates the hillsides are steep and rugged, and where sandstone is the cap rock the tops of the hills are broad and flat. The latter type of topography is well developed near Bonus, west of Foxburg, near Rimersburg, and generally in the northern part of the quadrangle. Elsewhere the rocks are prevailingly shaly, and the hills have rounded tops and gently sloping sides.

Another class of surface features consists of stream-cut terraces and abandoned channels, which are well developed along the lower part of the Clarion and continue down along the Allegheny below the mouth of the Clarion. They are developed to some extent also along Redbank Creek.

The Foxburg quadrangle is divided into three segments by Allegheny and Clarion rivers. The run-off from the western segment reaches Allegheny River by way of Sugar Valley, Bear Creek, Binker Valley, Crozier Hollow, and Birch, Armstrong, Whisky, Cove, and Pine runs, and numerous smaller streams and gullies. The principal streams in the northern segment are Shull Run, Mill Creek, and Richey Run, flowing into the Allegheny, and Turkey Run, Beaver Creek, and Canoe Creek, flowing into the Clarion. In the southeast segment the Allegheny receives water from Fiddlers, Black Fox, and Catfish runs, and several unnamed brooks; and the Clarion from Cherry Run and Licking Creek. A few small streams in the southeast corner of the quadrangle discharge into Redbank Creek, which flows parallel to the Clarion just off the southern boundary of the area.

Allegheny River is the most important artery of commerce. Though very little freight is transported by water, the river affords a very uniform gradient for the Pennsylvania Railroad, which follows a low narrow terrace along its eastern bank, and much local and through traffic is carried on along this route. The river flows in a narrow gorge and has a number of long curves. Therefore the railroad, in following the bank of the river in the bottom of the gorge, is much longer than if it followed a straight line; but the cost of building and operating the railroad over the long course, in which little cutting and filling was necessary, is less than would be the expense of building a line across interstream areas, or even tunneling through the narrow necks, such as that at Wood Hill.

The making of Allegheny River navigable is a project which has often been considered, and the Government has made surveys with that end in view. But no improvement work has been done, and it is only at high water that any boats enter the Foxburg quadrangle. At low water there are many riffles where the water is less than a foot deep. The longest and most formidable rapid in the Allegheny between Olean, N. Y., and Pittsburg is located 3 miles north of Emlenton. Its length is 6,900 feet, and the fall of water in this distance is 11.23 feet. Some timber is floated down the river on rafts, but almost all the freight along the Allegheny is handled by the Pennsylvania Railroad.

The Clarion is more crooked even than the Allegheny, and though there is in some places a very narrow terrace, which may correspond to the one followed by the railroad on the Allegheny, no railroad has been built along the stream. There are almost no public wagon roads in the bottom of the valley.

The valley of Redbank Creek is, however, used by the "Low-Grade division" of the Pennsylvania—so called because it crosses the mountains at a lower altitude than the main line, between Pittsburg and eastern cities. The stream is not so crooked as the Clarion and the valley is more open.

Bear Creek valley, in the southwestern part of the quadrangle, is used by a branch of the Baltimore & Ohio Railroad. This road is standard gage as far as Foxburg, and thence is a narrow-gage line, with many steep grades. It runs through St. Petersburg, Knox, and Shippenville, to Clarion Junction.

A short distance east of the quadrangle the Pittsburg, Summerville & Clarion Railroad finds a way over the comparatively smooth uplands between Clarion River and Piney Creek, and the Franklin & Clearfield Railroad has just been built along Deer and Piney creeks. A branch of the Pennsylvania Railroad, called the Sligo branch, runs near the boundary of the quadrangle from Redbank Creek to Sligo. Over this route the grade is steep, but the road forms an outlet for the product of several coal mines.

The relation of the coal beds and other underground economic resources of the quadrangle to the hills is such that over the greater part of the region no shaft mining is done. The coal is mined by drifting and the clay and lime by stripping. Iron ore, which was formerly an important product, was mined also by open-cutting, or in some places by drifting.

The majority of farm houses are located very near coal outcrops, not for convenient access to the coal, but because along coal outcrops there are many springs, and springs were generally determining factors in the early days in locating farm houses. Coal beds are commonly underlain by clay, and this forms an impervious layer, causing ground water to travel along it until the surface is reached, where the water appears in the form of a spring. It is not uncommon to see the coal itself exposed in such springs.

STRATIGRAPHY.

CHARACTER AND THICKNESS OF THE ROCKS.

The rocks of the Foxburg quadrangle are all of sedimentary origin and consist chiefly of shale, sandstone, clay, limestone, coal, and alluvial deposits of sand and gravel. With the exception of the coal, most if not all of the materials of which these rocks are composed were transported and deposited by water and many of them were laid down in an ocean. The various strata were thus deposited in successive layers, one above another, and were spread out over large areas, some of them having an extent of thousands of square miles.

The composition and thickness of each stratum varies greatly from point to point because of differences in local conditions under which it was laid down. In places the currents were strong; and the sand and mud brought down by streams was washed and assorted, the light, fine mud being borne away to settle to the bottom in areas where the water was comparatively still, the remaining sand being spread out only so far as the currents were strong enough to carry it. From time to time there were developed local conditions favorable for the growth of lime-secreting animals and plants, which, when they had died, left shells and other calcareous remains that in time accumulated in such quantities as to form beds of limestone. Thus, there were deposited various kinds of sediments which were afterward consolidated by pressure and cementation into rocks of various compositions and appearances. The sand became sandstone; the fine mud became shale (or clay); and the remains of animals, and perhaps of certain plants, became limestone. Coal was formed from accumulations of plant remains in swamps and lagoons, and fire clay probably from the old soil in which the plants grew. Under such conditions, it should be expected that the sandstone beds would grade into shale or clay, or even would be in the same stratigraphic position as limestone or coal. This is in fact true, though there are certain beds that are uniformly persistent over comparatively large areas and represent stages of deposition in which thousands of square miles of the sea bottom was covered by material of practically the same kind.

The total thickness of the sedimentary rocks, including both the exposed rocks and those which lie beneath the surface, varies greatly in different parts of the United States. Those of the Foxburg quadrangle are several thousand feet thick, so deep in fact that no drill has ever penetrated to the old granite floor below.

For convenience of description geologists have separated this column of rocks into several groups according to their age, and have designated these groups, and important beds contained in them, by names. Below is given a brief description of these beds so far as they have been recognized and named in the Foxburg quadrangle.

ROCKS NOT EXPOSED AT THE SURFACE.

All that is known of the rocks which are concealed below the surface of the Foxburg quadrangle has been secured from a study of these rocks in other areas where they are exposed, and from data obtained from deep wells drilled for oil and gas in the quadrangle. A number of these wells have penetrated more than 3,500 feet of rocks and some of them have probably gone through more than 2,500 feet of strata that are not exposed at the surface. Detailed records of only a few of these deep wells were secured, and the data furnished by them are too meager to furnish good descriptions of the lower beds. Only a tentative grouping of them can therefore be made. A general idea of the character of these rocks may be secured by an examination of Plates II, III, and IV, which show a number of detailed well logs platted to a scale of 400 feet to the inch and arranged with reference to the Third or Gordon sand as a datum plane.

DEVONIAN SYSTEM.

PORTAGE (?) FORMATION

The beds in western Pennsylvania which are assigned to the Portage formation by Butts[a] consist of about 1,000 feet of sandy shale and thin-bedded sandstone extending from the soft dark shale which is believed to represent the Hamilton formation upward to the top of the Bradford oil sand group of McKean County, Pa.

In the Foxburg quadrangle a number of deep wells have been drilled through a group of sands from 80 to about 200 feet thick, which are supposed to be equivalent to the Bradford oil sands, though this correlation is by no means positive. Of these deep wells only a few imperfect logs are now available. It is therefore evident that only the most general and tentative correlation can be made of the lowest rocks touched by the drill in these wells.

In the Bradys Bend well (No. 6 on Pl. II) no Bradford sand is recorded, but its horizon is probably about 350 feet below the top of

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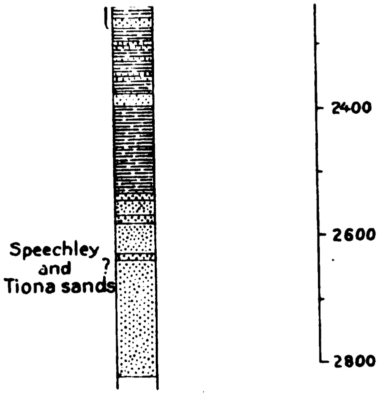
[a] Rept. Top. and Geol. Survey Comm., Pennsylvania, 1906-1908, p. 201.



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the Speechley sand as given in that section. This well probably penetrated over 900 feet into the Portage (?) formation, but the record was too poorly kept to be of stratigraphic value. From 150 to 300 feet of strata at the top of the formation are reported in a few wells made up of sandy chocolate to grayish shale and sandstone interbedded with from one to three sandstones of what is supposed to be the Bradford oil sand group. Below these sands the drillers generally describe the rocks as "slate and shells," being equivalent to shale alternating with thin, hard, sandstone layers.

In the Foxburg quadrangle there are usually two oil sands in what is here called Bradford (?) oil sand group. The first or uppermost sand has a maximum thickness of about 50 feet, but is usually not more than 20 feet. It is grayish or chocolate colored, and is generally fine-grained and hard, in most cases making a poor reservoir for oil or gas. The second oil sand of this group is usually separated from the first by 20 to 80 feet of sandy grayish or chocolate-colored shale. It is from 10 to 150 feet in thickness and usually grayish in color, though in some wells 20 feet of black sand is reported at the base. The second Bradford (?) sand is usually fine-textured and hard, but in a few cases it carries soft porous "pay" streaks, which, in a few places, contain gas.

CHEMUNG (?) FORMATION.

Beds of doubtful age.—Overlying the Portage (?) formation and extending upward to the base of the Devonian (?) red beds (Catskill (?) formation) are greenish or chocolate-colored shale and thin sandstones having a total thickness of 900 to 1,100 feet in the region of the Foxburg quadrangle. Butts[a] considers these to belong to the Chemung formation, but the evidence on this point is not conclusive, and therefore the beds are not here definitely assigned to that formation.

In other reports[b] M. J. Munn has tentatively placed the top of the supposed Chemung at the base of the lowest red rock reported in well logs, about 800 feet below the Third or Gordon sand. In the light of recent stratigraphic and paleontologic studies of these beds by Butts, it seems very probable that the thin beds of red rock mentioned by drillers at from 500 to 800 feet below the Third sand are really the chocolate or "Pink rock" of the drillers farther to the north, which is shown to be Chemung. It therefore seems advisable to consider the top of this formation as being between 200 and 400 feet below the Third or Gordon sand in the Foxburg quadrangle.

Tiona sand.—The lowest well-defined oil and gas bearing sand of the Chemung (?) is known to drillers as the Tiona sand. In the Foxburg quadrangle the top of this sand is from 180 to 200 feet above the so-called first Bradford sand. It ranges from a few inches to more than 100 feet in thickness, probably averaging not more than 30 feet. The sandstone is usually close-grained and hard, and hence of little value as a reservoir for oil or gas. In a few places within the quadrangle it is reported as carrying soft, porous, gas-bearing pay streaks, but the total yield of gas from this bed has been small. It does not seem to have produced oil in commercial quantities at any point in the quadrangle.

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[a] Rept. Top. and Geol. Survey Comm. Pennsylvania, 1906-1908, p. 200.

[b] Geology of oil and gas fields of Sewickley quadrangle, Pennsylvania, and geology of oil and gas fields of Clarion quadrangle, Pennsylvania, to be published by Top. and Geol. Survey Commission of Pennsylvania.

Speechley sand.—The top of this sand is from 100 to 150 feet above the Tiona sand. It ranges from a few inches to about 85 feet in thickness, and though a hard, close sandstone, it is in many places in the quadrangle sufficiently porous to afford storage room for large quantities of gas and some oil. It is usually found at depths ranging from 1,900 to 2,100 feet, the gas developing closed pressures of as much as 900 pounds per square inch.

Warren sand.—The upper half of the Chemung (?) in the Foxburg quadrangle is a mass of shale and thin layers of sandstone in which at certain places are found lenticular sandstones of considerable local thickness. The most prominent and persistent of these sandstones lies about 300 feet above the Speechley sand and is known to drillers as the Warren sand. This sand is reported in only a few wells, and in none of them is it known to have been productive. It probably varies from about 400 to 550 feet below the Third or Gordon sand and may in reality consist of sandstone lenses at slightly different horizons. No close correlation of this sand can be made, but it appears to be within 200 feet of the top of the Chemung, with chocolate or grayish shale and thin layers of sandstone above.

DEVONIAN (?) SYSTEM.

CATSKILL (?) FORMATION.

Shales and sandstones.—Upon the Chemung (?) formation lies 500 to 700 feet of red and green shales in which are interbedded white and gray and reddish sandstones. In some of the reports on areas to the south and east these shales have been included in what is here called Chemung, and in others they have been described as Catskill. To the north, in the Warren quadrangle, beds which overlie the Chemung, and which may be either Devonian or Carboniferous, are mapped as the Conewango formation (bottom) and the Knapp formation (top). The exact relations of these shales in the Foxburg quadrangle to the Catskill formation or to the Conewango formation have not been determined and in this report they will be called Catskill (?) formation. These beds include the lower part of the great oil and gas bearing group of sandstones known as the Venango oil sands, from which most of the oil of the Foxburg quadrangle has been obtained.

Correlation of oil sands.—Because of their great economic value, the correct correlation of the individual oil sands of this division over western Pennsylvania has often been attempted, and while these studies have in general settled the stratigraphic position of the more prominent sandstones, the work has not been done in sufficient detail to settle questions involving local variations. For the purpose of furnishing data which may be of value in such detailed stratigraphic work Plates II, III, and IV of well sections have been platted. A careful study of these sections will show the difficulty of tracing by well records alone a definite oil sand over any great area. It will be noticed that each of these beds not only varies greatly in thickness from well to well, but that in many places they disappear and are replaced by shale and in some places by red rock. In the Foxburg quadrangle none of these beds attain sufficient prominence or persistency to form a reliable datum plane, and in wells comparatively close together the variation is so great as to make any correlation questionable.

At Oil City, where the Venango oil sands were discovered and named, three distinct and clearly marked oil sands occur which were named by the operators the First, Second, and Third sands, in descending order. Later operations in that region developed a fourth sand of less extent and importance, overlying the original Third sand, which was called the Third Stray sand. In some portions of this field the First sand was also found to be made up of two sandstones separated by a few feet of shale.

Overlying the oil sands in the Oil City region are about 400 feet of soft shale, in which is embedded one or more thin beds of sandstone.

Below the Third sand in that region is soft shale for 200 or 300 feet, which in few places, if anywhere, contains sandstone of sufficient thickness to be recognized.

When drilling was begun in Butler and Armstrong counties, the same names were applied to sands found by the drillers which seemed to them to correspond to those found at Oil City, but unfortunately the sands do not correspond. The result was that what is known as the Venango First sand is equivalent to the Butler County Second sand or Hundred-foot, and the Third sand of Butler County seems to be more nearly comparable to the Second sand of Oil City and the Venango Third to the Butler Fourth sand. The exact correlation of the oil sands of these two fields is not to be solved as easily, however, as one might be led to infer from this statement. The chief difficulty to such a correlation lies in the fact that southeastward from Oil City the 300 to 380 feet of strata embracing the three Venango sands show a marked tendency to develop other fairly persistent sandstone lenses which, because of their close vertical range, similar lithologic character, and equal thickness, render continuous tracing of the beds from one section to the other by well logs extremely difficult.

Some idea of the uncertainty of such close correlations may be secured by a minute comparison of the sections shown on Plates II, III, and IV. If it be remembered that the factor of error in measurement must be considered, always, in making comparisons of these logs, the extreme difficulty of correlating positively the Third sand of one section with that of another even for only a few miles distant can readily be understood. In such close correlations of the lower portion of the Venango oil-sand group it must be remembered that oil developments did not as a rule expand from a single well, but that there were in reality several foci of growth, which in many cases developed marked variations in the number of sands found, in the intervals separating them, in the position and thickness of guiding beds of red rock, and in distance from the surface bed from which the distance to the oil sands was calculated. Considering these elements of uncertainty and the fact that more than a third of a century has elapsed since the large fields of the Foxburg quadrangle were first developed and that nearly all of the data then obtained have since been scattered and lost, the correlations suggested on Plates VI, VII, and VIII can be considered only tentative ones.

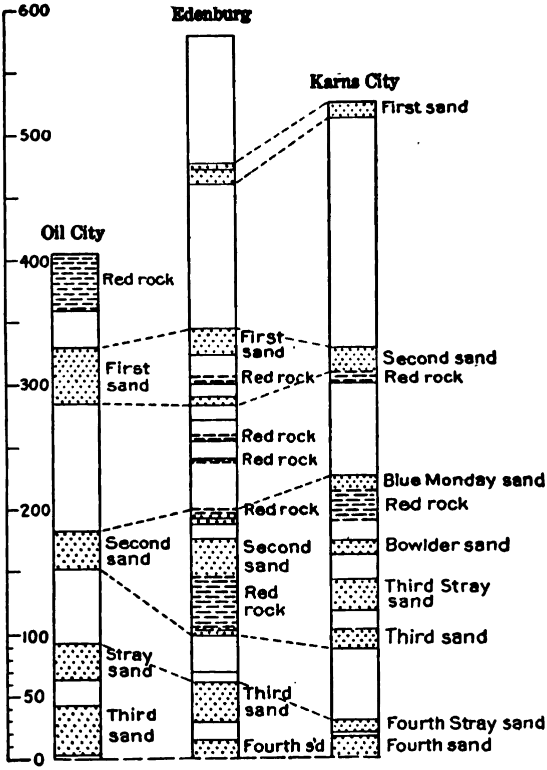

FIGURE 1.—Well section showing correlation of sands (by Carll).

Considerable attention was given by Carll[a] to a correlation of the oil-bearing sands of western Pennsylvania. In 1880 he traced the oil sands in a line of wells from Oil City to Edenburg in the Foxburg quadrangle, and thence southwest to Karns City near the southwest corner of that quadrangle. The records of a number of wells were used in this work and several typical sections were drawn to scale

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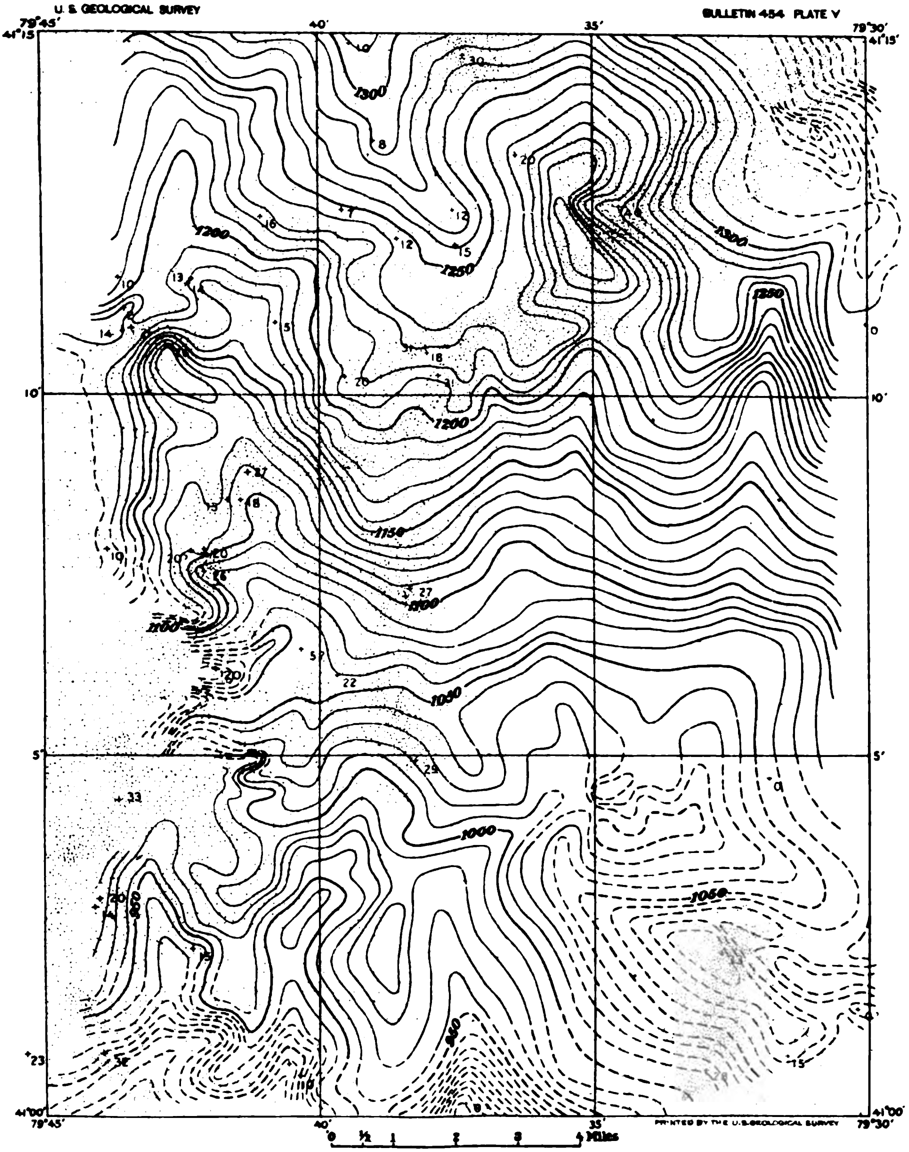
[a] Second Geol. Survey Pennsylvania, vols. I, II, III, I4, I5, H5.



SKETCH MAP SHOWING THICKNESS, EXTENT, AND STRUCTURE OF THE THIRD OR GORDON SAND IN THE FOXBURG QUADRANGLE, PENNSYLVANIA

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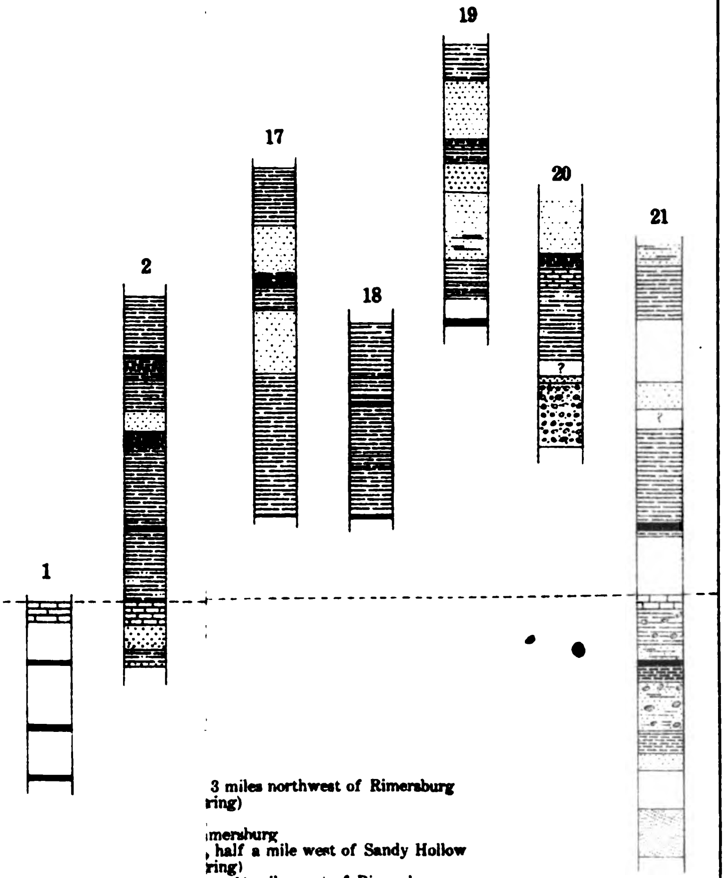
Pattern showing variation in thickness of Third or Gordon sand
Greater or less thickness is shown by difference in density of dotted pattern: The more dots the greater the thickness. In undotted areas the sand is absent or has not been recognized. Numbers show thickness of sand in feet at points indicated by crosses

Structure contours on top of Third or Gordon sand
Contour interval 10 feet; datum plane 1000 feet below sea level



3 miles northwest of Rimersburg
ring)

mershurg
, half a mile west of Sandy Hollow
ring)
m, 1½ miles east of Rimersburg
ring)
m, 2 miles west of Rimersburg
ring)
ens

quadrangle

░ Sand or sandstone
⁘ Conglomerate or gravel
● Concretions

150 Feet

HE CLARION RIVER

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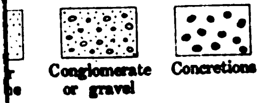

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and published.[a] Of these he selected the following three sections as indicative of the change in the stratigraphy and nomenclature of the Venango oil-sand group from Oil City southeastward. In the main this work by Carll is considered to be correct, as shown by the following figure reproduced in a slightly different form from his report.

It will be seen from these figures that the First sand at Oil City is considered by Carll to be equivalent to the First sand of the drillers at Edenburg and their Second sand at Karns City. Also the Second sand of Oil City is equivalent to three sands including the drillers Second sand of Edenburg, and their Blue Monday, Bowlder, Third Stray, and Third of Karns City. In like manner he considers the Third Stray of Venango County equivalent to the Third of the drillers at Edenburg and the Fourth Stray of Karns City, the Third sand of Oil City being equivalent to the Butler Fourth sand at Karns City.

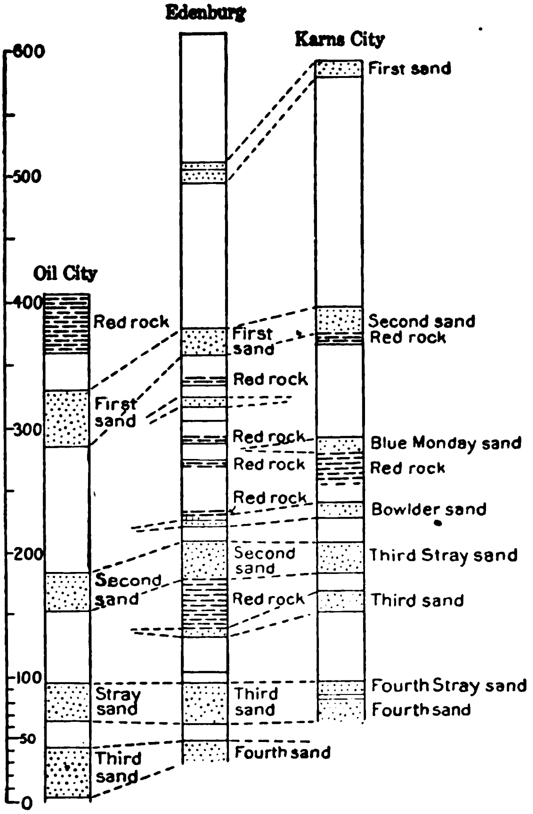

FIGURE 2.—Well section showing possible correlation of the sands in the same wells as shown in figure 1.

From a study of the well sections shown on Plates II, III, and IV the writer believes that the correlation of the sands of the sections in figure 1 by Carll is more nearly correct as shown in figure 2, in which it will be seen that the Venango First sand of Oil City is equivalent to the Butler Second sand at Karns City; the Venango Second sand is equivalent to what in this particular well is termed the Third Stray sand at Karns City, and the Venango Third Stray sand is the Butler Fourth Stray and Fourth combined at Karns City. This correlation therefore makes the original Venango Third sand equivalent to the Fourth sand at Edenburg, and to the Butler Fifth sand, not shown in these sections. The third section of the above figures is the McClyman farm well, near Karns City, the complete section of which is shown as No. 1 of Plates II, III, and IV, and from a comparison of the sections in those plates a wider correlation with Venango oil sands may be made.

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[a] Carll, Second Geol. Survey Pennsylvania, vol. III, p. 178.

At Petrolia this group of sands has a minimum thickness of about 300 feet and is composed in ascending order of the Butler Fourth, Fourth Stray, Third, Third Stray or Gordon Stray, Bowlder, Nineveh, Thirty-foot, Fifty-foot, and Second sands, the First sand of this vicinity being regarded as equivalent to the Sharpsville sandstone member of the Cuyahoga formation and as lying about 185 feet above the top of the true Venango oil-sand group. It should therefore be grouped with distinctly younger beds. Farther to the east the Fifth sand comes in as a lenticular sandstone, underlying the Fourth at a distance of from 40 to more than 100 feet.

Butler Fifth sand.—In the Foxburg quadrangle the Fifth sand in few places reaches a thickness of more than 30 feet. It is generally a fine-grained white to grayish sandstone, hard, but in places containing thin streaks of softer, porous, somewhat pebbly sand, carrying more or less gas. It seems to be absent over the northwestern half of the quadrangle and in general is found to be thickest and most persistent in the southeastern part.

On Plate II the Fifth sand is called the Fourth sand in section 6, the true Butler Fourth sand being absent. From this point eastward the sand is noted in the four wells drilled to that horizon. In section 11 the Fifth sand is probably equivalent to what is called the Fourth sand by the driller. The enormous sandstone designated by the driller as "limy sand" is such an uncommon thickness of sandstone at this horizon that its presence is to be taken with due allowance for error which might have been made by the driller in classifying the rock. Numerous well-kept records in the immediate vicinity of this well report only a normal thickness of 10 to 30 feet of Fifth sand, the underlying beds being designated as "slate and shells." The rocks occupying this interval, whatever they may be, are near the top of the Chemung.

Butler Fourth sand.—The Fourth sand overlies the Fifth from 40 to over 100 feet, the interval being filled by soft shale. This is prevailingly green with thin red streaks in the vicinity of Petrolia, but eastward the red rock increases in thickness until in places it occupies the whole interval between the sands. The Fourth sand ranges from less than 10 feet to more than 50 feet in thickness. It is usually white, with soft, porous pay streaks from which enormous quantities of oil have been secured at many places in the quadrangle. Toward the north and northeast the identity of the Fourth sand is not always clear, as may be seen from an examination of the well-section plates.

In many places where the Third Stray sand is wanting the Fourth has possibly been mistaken by drillers for the Third and vice versa.

Butler Third or Gordon and the Butler Third Stray or Gordon Stray sands.—These two sands taken together are fairly persistent beds throughout this quadrangle, but much difficulty is experienced in positively identifying and tracing them by means of well records. This is due in many cases to local variations in thickness of the sands, to their varying distance from the Vanport limestone member, and other marking strata, and to the variation in position and thickness of the beds of red rock. In general these sands have a combined thickness of a few inches to 75 feet. (See Pl. V.) They are absent over much of the eastern part of the quadrangle, in Licking, Perry, Toby, southern Beaver, and parts of Madison townships, Clarion County, and along the southern border of Perry Township, Armstrong County. In many places in this area these sands are represented only by thin beds of hard sandstone embedded in soft green or red shales, and in such places they have been found to contain little or no oil or gas. The thickness and extent of this sand is shown on Plate X (in pocket).

The Third and Third Stray sands are well developed along a broad belt from Petrolia to Elk City and throughout most of the northwest half of the quadrangle. In this region the bottom of the Third sand is from 40 to 80 feet above the Fourth sand, the interval being usually occupied by dark green and red shales and some red rock. Toward the southeast this distance increases to about 120 feet, and in many places it is occupied mostly by red shale. The Third and Third Stray sands are usually soft, white, pebbly, and loosely cemented, and offer fine reservoirs for the enormous quantities of oil and gas which have been found in them.

Bowlder sand, Snee or Blue Monday sand, and Nineveh Thirty-foot sand.—Throughout the quadrangle and to the southwest these names are used interchangeably to designate from one to three thin sands overlying the Third Stray. In fact the name Bowlder is often applied to the Third Stray itself. Perhaps the widest usage is to designate in ascending order the first three sands above the Third Stray, when all are present, as the Bowlder, Snee or Blue Monday, and Nineveh Thirty-foot sands. Where they occur within 150 feet of the top of the Third Stray sand, the names are probably correctly applied, but if the interval is much greater than 150 feet the uppermost of the three sands is more likely to be equivalent to the lower member of the Hundred-foot (Butler Second or Venango First) sand. Each of these three sands seldom exceeds 25 feet in thickness, but all are subject to rapid local thickening to 60 or 80 feet. They are white or gray, in many places soft and pebbly, and are both oil and gas bearing. The Thirty-foot sand is considered by Butts[a] to be the uppermost sandstone of the Knapp formation, the boundary being fixed by him at or near the base of the Hundred-foot sand, the former including the red shale interval between the Hundred-foot and the Nineveh Thirty-foot sands.

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[a] Rept. Top. and Geol. Survey Comm. Pennsylvania, 1906-1908, p. 1999.

CARBONIFEROUS SYSTEM.

POCONO GROUP (LOWER PART).

The Pocono group overlies the Catskill formation, and includes from 700 to 900 feet of sandstone and shale from the base of the Hundred-foot sand to an unconformity at the top of the Burgoon sandstone (Big Injun or Mountain sand of the drillers).

The basal member of the Pocono group is one of the great sandstones of the Appalachian province, for it underlies thousands of square miles in Ohio, Pennsylvania, and West Virginia. Recent studies by Butts[a] seem to show that the Butler County Second sand is equivalent to the Venango First oil sand and the Berea sandstone of northern Ohio. In the Foxburg quadrangle the Butler Second apparently divides into the Hundred-foot sand below and the Murrysville or Butler gas sand above. The Hundred-foot sand is divided into the Gantz and Fifty-foot sands in southern Allegheny and Washington counties. Westward into Ohio in the vicinity of Beaver and to the southwest, the Murrysville or Butler gas sand apparently is the same as the Berea oil sand, and if so, is equivalent to the upper portion of the true Berea sandstone of northern Ohio. However, this point is not definitely settled, and it is possible that further studies will show that the Berea oil sand of southeastern Ohio and Pennsylvania is really equivalent to the Butler First, which is the first persistent sand overlying the Murrysville gas sand.

In the Foxburg quadrangle the Hundred-foot sand is in places separated into as many as five different sandstones, embedded in soft shale, some of which is red. The topmost member of this group, which is frequently called the First sand, lies from about 200 to 350 feet above the top of the Butler Third sand, this variation occurring between Petrolia and the eastern border of the quadrangle. (See Pl. II.) The sands are gray, white, and sometimes dark in color. They are usually hard and close, but in many places carry lenses of soft, pebbly sand containing oil, gas, and salt water.

In the Foxburg quadrangle from 400 to 500 feet of soft gray, green, and infrequently red shales overlie a sand commonly known to drillers of this locality as the First or Venango First sand. This shale is generally recognized by drillers because it affords a zone of easy drilling between the Burgoon sandstone above and the Venango oil sands below. The upper 20 feet of this shale outcrops in the bottom of the Allegheny gorge and has been correlated, both from lithology and from contained fossils, with the Meadville shale member of the Cuyahoga formation. Embedded in this shale are one or more persistent beds of sandstone. The most important of these is generally from 10 to 40 feet and locally 100 feet or more in thickness, and divides the shale into two fairly equal divisions. In the lower shale division occurs another sandstone in the Foxburg quadrangle, which is probably equivalent to the Butler First sand. This sandstone apparently pinches out northwest but increases in thickness and stratigraphic importance east, south, and southwest. Some oil and gas have been found in both these sands in the Foxburg quadrangle, but the total quantity was relatively small. Above this sandstone the shale is darker and more reddish, thin beds of "red rock" being frequently reported.

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[a] Rept. Top. and Geol. Survey Comm. Pennsylvania, 1906-1908, p. 195.

Above this shale is the Burgoon sandstone, a great mass of sandstone known to drillers as the Mountain or Big Injun sand. All of these overlying rocks outcrop at the surface within the Foxburg quadrangle, and are therefore discussed below under "Outcropping Rocks."

OUTCROPPING ROCKS.

CARBONIFEROUS SYSTEM.

With the exception of the unconsolidated Quaternary stream deposits the rocks which outcrop in the Foxburg quadrangle belong to the Mississippian and Pennsylvanian series of the Carboniferous system. They are classified as follows:

- Carboniferous system.
  - Pennsylvanian series.
    - Conemaugh formation.
      - Mahoning sandstone and overlying shale.
    - Allegheny formation.
    - Pottsville formation.
      - Homewood sandstone member.
      - Mercer shale member.
      - Connoquenessing sandstone member.
  - Mississippian series.
    - Pocono group.
      - Burgoon sandstone.
      - Cuyahoga formation.
        - Meadville shale member.

The rocks will be described in order of deposition.

MISSISSIPPIAN SERIES.

POCONO GROUP.

CUYAHOGA FORMATION.

The outcrop of the Cuyahoga formation occupies a limited area in the bottom of the Allegheny gorge between Emlenton and Wood Hill. The best exposure is in a cliff on the west side of the river 1 mile north of Dotter Station, or 5 miles north of Emlenton. At this point about 20 feet of dark-gray sandy shale are laid bare and in the uppermost foot or so there are more or less numerous pebbles. The layer bearing these pebbles is considered as marking the top of the formation. A mile farther north the top of the formation lies about 37 feet above low water, but at this point most of the section is concealed.

In the northwestern part of Pennsylvania there are many good exposures of the Cuyahoga, and it has been divided into three members: The lower one has been called the Orangeville shale; the middle one has been called the Sharpsville sandstone; and the upper member is known as the Meadville shale. The part of the Cuyahoga which outcrops in the area under discussion belongs to the uppermost or Meadville shale member.

BURGOON SANDSTONE.

The Burgoon sandstone, named from Burgoon Creek, in Cambria County, Pa., is irregular in most characters, but consists principally of sandstone, though it also includes considerable amounts of shale. Where exposed in the Foxburg quadrangle this sandstone, which is known to the drillers as the Mountain or Big Injun, sand is not evenly bedded, though layers 4 to 6 inches thick are common. On weathering the shale crumbles and is washed away, leaving slabs of sandstone, which make the outcrop appear like ruins of old masonry. The sandstone is generally coarse and not very pure. In some places, as near Foxburg, it displays considerable cross-bedding. Lenses of shale of all sizes ranging up to 60 feet or more in thickness are included, and in the lower part of the formation this rock predominates. The shale is light-gray or greenish, soft, and more or less clayey.

The formation outcrops along the gorges of the rivers and in many of the tributary valleys. It is almost devoid of fossils. In some places there is a layer of carbonaceous shale, or even thin coal, near the top, which contains plant remains. The entire formation is exposed, and the thickness is 300 to 320 feet. The lower limit is believed to lie at the top of the peculiar conglomerate previously mentioned as forming the uppermost layer of the Cuyahoga formation. The upper limit of the Burgoon is not marked by any stratum which is everywhere recognizable. Several factors are commonly employed in locating the boundaries between it and succeeding formations. The coaly layer previously referred to is, when present, about 15 feet below the top of the Burgoon. A somewhat similar coaly bed lying at many places between beds of heavy resistant sandstone is found about 40 feet above the boundary. The horizon of the Brookville coal is about 130 feet and that of the Vanport limestone member, to be described later, about 240 feet above the top of the Burgoon.

The indistinctness of this upper limit of the Mississippian is remarkable when we consider that there is good evidence of a great unconformity at this horizon. Probably hundreds of feet of Mississippian strata were eroded from this region before the deposition of the Pennsylvanian, but that erosion left such a smooth surface and the succeeding strata were so much like those below, that in few places, if anywhere, can the unconformity be located with exactness. For example, along the "brick road" opposite Emlenton is a very good exposure of the Mississippian and the Pennsylvanian strata adjacent to the unconformity, but there is no pronounced break discernible. There are many minor breaks, and it is probable that one of these is the unconformity. One break in particular lies at the top of an irregular layer of sandstone which has certain vertical markings, suggesting that cracks had formed after the sand had consolidated and before the succeeding strata were laid down upon it. These cracks apparently filled with sand when the layer above was deposited, but the data are not considered decisive.

MAUCH CHUNK FORMATION.

The uppermost Mississippian formation, the Mauch Chunk, is not present in this quadrangle. It is thought that it was deposited and eroded in the period of time represented by the Mississippian-Pennsylvanian unconformity. At Mauch Chunk the formation is 2,200 feet thick, but it thins to the west to 180 feet at the Allegheny Front and to 250 feet in the southwestern part of Pennsylvania. This thinning is probably due in part to erosion.

PENNSYLVANIAN SERIES.

POTTSVILLE FORMATION.

Definition.—Although the Mauch Chunk formation has been eroded from this area, and the Pottsville rocks lie unconformably on the Burgoon sandstone, the line of separation is not lithologically clear, and fossils are very scarce. In many places thick-bedded sandstones are found both at the top of the Burgoon and at the bottom of the Pottsville. Such sandstones are very similar, both in megascopic and microscopic characters. The grains of sand are of approximately the same size and equal degree of rounding. The only visible difference is that the sandstone of the Pottsville formation is, as a whole, somewhat thicker-bedded, slightly coarser, and approaches more closely to pure silica.

The upper limit of the Pottsville, like the lower, is difficult to determine in the field. Its approximate position can be located without difficulty, for it is above the sandstone just mentioned and below the Brookville coal; but difficulties arise from the fact that just between the sandstone and the coal there is generally a variable thickness of shale and also from the fact that the coal is absent throughout considerable areas. However, the coal bed holds a fairly uniform position with reference to other recognizable strata, so that its horizon can be located when it is absent. In the Foxburg quadrangle the upper boundary of the Pottsville is drawn at the base of the clay underlying the Brookville coal and known as the Brookville clay.

The Pottsville formation is found along the gorges of the rivers just above the Burgoon sandstone, and extends a mile or two farther up the tributary streams. On Mill, Beaver, Canoe, Licking, and Bear creeks, and on Turkey and Cherry runs its upper limit varies from 4 to 7 miles from the main stream. At the north boundary the Pottsville is 470 feet above the river and at the south boundary it is only 175 feet. Along the Clarion gorge it extends from 260 to 350 feet above the stream.

Connoquenessing sandstone member.—The Connoquenessing sandstone, the lowest member of the Pottsville formation in this region, is a thick-bedded, resistant, saccharoidal sandstone which varies in color from buff to white and is nonfossiliferous. Some layers are not well consolidated, and appear much like granulated sugar. On the whole, the rock is very pure and free from everything but silica. On account of these characters it is extensively quarried for glass sand and silica brick. The beds are more or less lenticular, but one at the top of the member can be traced over a considerable area in the northwest part of the quadrangle. This is a very resistant layer 3 to 6 feet thick, and is overlain by a shaly coal 4 inches to 2 feet 6 inches thick. The thickness of the Connoquenessing sandstone ranges from 30 to 50 feet.

Mercer shale member.—In the midst of the Pottsville formation there is a series of shales, thin coals, and clays which have received the name Mercer, because in Mercer County the member is a prominent part of the section and one of the coal beds is worked. The coal is locally workable elsewhere, and in some places the member contains a valuable bed of refractory clay. In this quadrangle the coal is not workable, and the clay seems to be of little value. The coal, however, is usually present in one or more beds, which vary from an inch or less to 16 inches in thickness.

The thickness of the Mercer shale member varies from 6 inches to 40 feet or more. In the northwest part of the Foxburg quadrangle the member seems to be represented by only 6 inches to 2 feet of coaly shale. Fossils of the Mercer member consist almost entirely of plant remains, and are comparatively abundant. They are very distinctive.

Homewood sandstone member.—The Homewood sandstone, the topmost member of the Pottsville, is a coarse-grained, massive sandstone, averaging about 40 feet in thickness. In some places, however, the member is represented by shale. This seems to be the condition near Parker. In the Foxburg quadrangle the Homewood is generally a clean white, finely cross-bedded, and loosely cemented sandstone. In the more or less weathered outcrops the member is very white and porous and the cross-bedding is a prominent feature, the rock resembling a thin-bedded sandstone tilted to a high angle.

ALLEGHENY FORMATION.

Character and thickness.—The Allegheny formation is composed of shale and sandstone, interbedded with coal, clay, and limestone. Economically it is by far the most important formation of those which outcrop in the area. In earlier reports on this area it was called the "Lower Productive Coal Measures," but it is now called the Allegheny formation, from the river along which it is typically developed. Coarse sandstone is much less prominent than in the Pottsville and Burgoon formations, and in some localities no heavy beds of sandstone occur. The shales are predominantly brownish, owing to a large content of iron oxide, but olive tints are conspicuous in the central and upper part.

The thickness of the Allegheny is from 345 to 370 feet, and it extends from the top of the Pottsville to the top of the Upper Freeport coal. The formation is much more uniform in thickness than would be indicated by the variations of the members. In a general way, there is a slight thickening to the northwest. The outcrop occupies a far larger area than that of any other formation in the quadrangle.

It is not possible to make a tabular section of the Allegheny formation which will apply over the whole area, because the succession of strata varies considerably. On a basis of lithologic character the Allegheny formation in the Foxburg quadrangle is naturally divisible into three parts. The boundary between the northeastern and the central parts runs from about 1 mile south of the point where Clarion River enters the quadrangle through a point about midway between Turkey City and Monroe to 1 mile southwest of Lamartine, and thence slightly east of north to the boundary of the quadrangle. Between the central and the southern segments the line runs through Huey, 1 mile south of Toby, 1 mile north of West Monterey, and thence through Bruin to the western boundary of the quadrangle. The following are generalized sections of the Allegheny formation in these divisions:

Generalized section of Allegheny formation in northeastern segment of Foxburg quadrangle.

Kind of rock.	Range.	Average.
	Feet.	*Feet.*
Shale, light gray, sandy	35	35
Coal, Lower Freeport	0- 3	2
Clay, Lower Freeport	4- 6	5
Sandstone, buff, and shale, sandy	50	50
Coal, Upper Kittanning	0- 3	2
Clay	0- 6	4
Shale, olive, with lenses of sandy shale and sandstone	35	35
Coal	1½	1
Shale, dark gray, with lenses of sandstone	30	30
Coal	0- ¾	½
Shale, brownish gray, and thin buff sandstone	30	30
Coal, Lower Kittanning	2- 3	2½
Clay, Lower Kittanning	4-10	7
Shale, brownish, and sandstone, pinkish	20	20
Coal	0- 2	1
Clay and iron ore	0- 6	4
Sandstone and sandy shale	20	20
Coal, Upper Clarion	0-13	2
Shale	4-15	8
Coal, Lower Clarion	2- 4	3
Clay, Lower Clarion	3-12	8
Shale, with thick layers of coarse sandstone	30	30
Coal, Craigsville	0- 1½	1
Shale, and sandstone, shaly	32	32
Coal, Brookville, with thick partings of sandstone, brown shale, and cannel shale	6-18	12
Clay, sandy, Brookville	8-15	12
		357

Generalized section of Allegheny formation in central segment of Foxburg quadrangle.

Kind of rock.	Range.	Average.
	Feet.	*Feet.*
Coal, Upper Freeport	3½- 5½	4
Clay, Upper Freeport	4 -10	7
Limestone, Upper Freeport, and iron ore	0 - 8	4
Sandstone, coarse to fine, and shale	35 -45	40
Coal, Lower Freeport, with shale parting of 2 feet	3 - 7	5
Clay, Lower Freeport	0 - 6	3
Sandstone, coarse, with lenses of shale in lower part	35 -60	45
Coal, Upper Kittanning	0 - 3	2
Clay	0 -10	3
Shale, light to dark gray, and sandy shale	40 -60	55
Coal, Middle Kittanning	10 -18	1
Clay	0 - 6	2
Shale, sandy, and sandstone, thin	30 -45	40
Coal, Lower Kittanning	0 - 2	1
Shale and sandstone, thin	20 -45	35
Limestone, Vanport, and ore	0 -20	9
Shale, with concretionary iron ore	2 -30	12
Coal, Upper Clarion	1 - 3	2
Shale, hard gray to black	7 -20	12
Coal, Lower Clarion	2 - 6	4
Clay, Lower Clarion	2 -10	7
Sandstone, thick coarse, and shale, brown	25 -35	30
Coal, Craigsville	0 - 3	1
Clay	½- 2	1
Shale	20 -35	35
Coal, Brookville	0 - 2	1
Clay, Brookville, sandy clay and clay shale	6 -12	8
		369

Generalized section of Allegheny formation in southern segment of Foxburg quadrangle.

Kind of rock.	Range.	Average.
	Feet.	*Feet.*
Coal, Upper Freeport	0- 5½	3
Clay, Upper Freeport	3- 8	5
Limestone, Upper Freeport, and ore	0- 6	4
Sandstone, thin, and shale, gray	30-45	35
Coal, Lower Freeport	0- 4	2
Clay, Lower Freeport	0- 6	2½
Sandstone, coarse, ranging to fine gray conglomerate, with a little shale	30-60	40
Coal, Upper Kittanning	0- 8	2
Clay, Upper Kittanning	0- 5	2
Sandstone, sandy shale, and shale	35-50	40
Coal, Middle Kittanning	0- 2	1
Clay, Middle Kittanning	0- 6	3
Shale, olive, and sandstone, thin-bedded gray	20-40	30
Coal, with shale partings	0- 2	½
Shale, sandy	35-60	45
Coal, Lower Kittanning	2- 4	3
Shale, and sandstone, thin	25-45	30
Limestone, Vanport, and ore	0-18	9
Shale	20-40	30
Coal, Clarion	1- 5	3
Clay, Clarion	3- 8	5
Sandstone, coarse	0-15	6
Shale, with thin layers of sandstone	15-25	20
Coal, Craigsville	0- 2	1
Shale	20-30	25
Coal, Brookville	0- 2	1
Clay, Brookville	3-12	7
		355

The economic value of certain beds of the Allegheny formation warrants a detailed description of the various members.

Brookville coal.—Lying above the Pottsville formation, and separated from it by a few feet of clay, clay shale, or argillaceous sandstone, is the Brookville coal. This bed is generally too thin to be workable, but locally it reaches a thickness of 2 feet or more. In places it is so free from sulphur that it has been used as a blacksmith coal. There is usually a peculiar argillaceous sandstone below or within the coal bed. Generally the underclay is very sandy and contains impressions of plant roots. Near Blairs Corners small lenses of argillaceous sandstone and partings of shale in and near the coal are especially abundant. The shale varies from cannel coal to a rock that is scarcely, if at all, carbonaceous. Four of these partings persist and thicken to the north, so that at the road exposure 1 mile east of Knox it seems to be 18 feet from the top to the bottom of the Brookville coal.

Craigsville coal.—In a few places in the Kittanning quadrangle a coal occurs between the Brookville and the Clarion which has been named the Craigsville on account of its development near the place of that name. It lies 40 or 50 feet below the Vanport limestone member and 40 or 50 feet above the Brookville coal. In the Foxburg quadrangle, which joins the Kittanning on the north, a coal was found about 55 to 70 feet below the Vanport limestone and 20 to 30 feet above the Brookville, and it is assumed that this bed is the Craigsville coal. The interval between it and the Brookville is generally filled with brown shale, containing much iron sulphide, carbonate, and oxide, usually in the form of concretions. In some districts there is more or less sandstone in the interval. The coal is generally thin, and in a few places only is it underlain with clay. It is of irregular development and general distribution. Near Callensburg and northward to Knox it is very well developed, but is absent over much of the western part of the area.

Lower Clarion coal.—The interval between the Craigsville coal and the Lower Clarion coal, the next coal above, is generally occupied by shale, but in much of the southwestern quarter of the Foxburg quadrangle the Craigsville is absent, and a coarse, thick-bedded, resistant sandstone 5 to 20 feet thick is found 2 to 10 feet below the Lower Clarion coal. This sandstone so much resembles the typical Homewood sandstone member that in the older surveys it was in some places supposed to be that stratum; in other places it was called Clarion sandstone.

Over most of the area of its occurrence the Clarion coal is known as a single bed. In 1880, however, Chance called attention to an apparent split in this bed, which takes place in Clarion and Venango counties (Second Geol. Survey Pennsylvania, Rept. VV, p. 50). The evidence gathered for this report sustains the view of Chance, but the members now known as Upper and Lower Clarion coals do not spread apart as regularly as was suggested in that work. The distance between them is variable, in some places reaching as much as 25 feet. The boundary of the area in which the separation takes place seems to pass near Bruin, for there is but a single Clarion coal bed south of that town, whereas to the north there are two, and in a section at Bruin there is a parting of over a foot of shale.

The Lower Clarion coal is recognized in the field by its position, thickness, sulphur content, and binder. It lies about 40 to 70 feet above the Brookville coal and 20 to 50 feet below the Vanport limestone member. The bed is of workable thickness almost everywhere through the Foxburg quadrangle and is as a rule the thickest coal below the Vanport limestone. It is nowhere free from iron pyrite and partings. A ½-inch to 2-inch binder near the middle of the bed is of wide extent.

In roadside outcrops the coal is generally thin, with several feet of white plastic clay beneath. This clay has not been worked, but appears to be of very good quality.

Upper Clarion coal.—The upper division of the Clarion coal is separated from the lower by a body of shale from 2 to 25 feet thick, and a similar body of shale separates it from the Vanport limestone above. In most sections there is no underclay, but the coal rests directly upon a hard, black, nonfissile mudstone. With the exception of a few places where there is a layer of sandstone the strata between the

Clarion coal beds consists of dark-gray shale, which on weathering turns brown.

The Upper Clarion coal is workable throughout much of the area where it is found, but in the Clarion quadrangle it is thin or absent. On the whole the quality seems to be somewhat above that of the Lower Clarion.

Vanport limestone member.—The Vanport limestone, sometimes designated "Ferriferous" limestone, is one of the most persistent and best known strata of western Pennsylvania. It takes its name from the town of Vanport, Beaver County, Pa., where it is typically developed. Wherever it is found, it is a valuable key rock for identifying other beds and for determining the position of oil and gas sands. The top of the limestone is 110 to 130 feet above the base of the Allegheny formation, the average distance being about 120 feet.

Most of the interval between the Clarion coals and the Vanport limestone is occupied by dark drab shale, which contains numerous iron nodules. In much of the area a coarse sandstone lies immediately below the Vanport and is generally 1 or 2 feet thick, but locally is much thicker. In many places there is no sandstone below the Vanport, and the Upper Clarion coal lies almost immediately under the limestone.

In quality the Vanport limestone is very pure, an analysis showing nearly 95 per cent carbonate of lime with little magnesia. The rock is dark-gray in color and fossiliferous. Brachiopods and fragments of crinoid stems are abundant, and corals, pelecypods, and gastropods are common. All of these fossils indicate that the rock is of marine origin. The average thickness of the limestone is about 10 feet, but this increases to 20 feet south of Callensburg. The rock is generally broken both horizontally and vertically by seams, which under light cover cause the limestone to weather into large bowlders. Near or at the top of the limestone there is commonly a band of chert about 1 foot thick. This chert, because of its resistance to weathering, indicates the presence of the limestone at many places where the limestone itself can not be seen.

Immediately above the limestone is a layer of iron ore in the form of siderite or limonite. The cherty layer which is found between the ore and the limestone has given the former the name buhrstone ore, a term frequently used in Pennsylvania. Exposures in limestone quarries reveal only a few inches of the ore, and in some places, as, for example, 2 miles northwest of Knox, the ore is very fossiliferous.

The limestone is found almost continuously along Allegheny River and along the Clarion up as far as Callensburg, lying 100 feet or so higher than the old high terraces or very near the top of the valley bluff. It is found also along most of the smaller streams.

In considerable areas, however, as shown in figure 3, the limestone is absent. Whether calcareous material was never deposited or was deposited and eroded before the succeeding sediments were laid down is unknown, but certain facts indicate that the limestone never existed in the areas where it is now absent. First, such areas are rounded and smooth in outline, and thus do not resemble the usual products of stream erosion or wave cutting. Second, near the boundary of such limestone areas the strata below seem to thicken at the

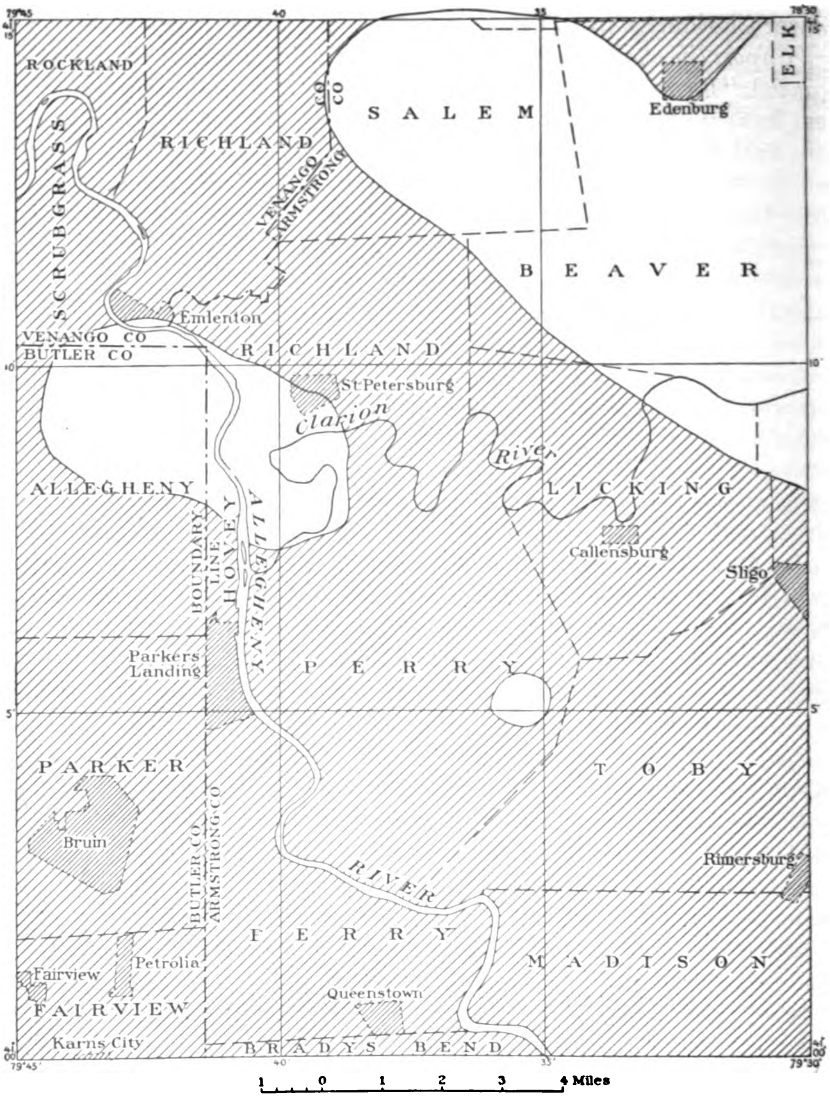

Figure 3.—Map showing original extent of Vanport limestone member in Foxburg quadrangle. Shaded portion indicates area in which Vanport limestone occurs. Darker shading shows towns.

expense of the limestone and to occupy its position. For example, 2½ miles south of West Freedom and 1 mile north of Concord Church, a coarse sandstone seems to have been deposited contemporaneously with the limestone and take its place in the horizon. Third, the general varied character of the Carboniferous strata in western Pennsylvania shows that there was contemporaneous deposition of different kinds of sediment in different places. Fourth, as Butts has pointed out, the limestone is found over large areas as a very thin stratum, and it seems hardly possible that erosion would have proceeded in such places just far enough to have removed all but the thin layer of limestone remaining. It thus seems more reasonable to assume that the districts in which the limestone is thin or absent either projected temporarily above water or that wave action prevented for a time the accumulation of calcareous sediments.

The interval between the Vanport limestone member and the Lower Kittanning coal is occupied by sandy shale and beds of sandstone of variable thickness.

Kittanning sandstone member.—In the large area in the northern part of the quadrangle wherein the Vanport limestone member is absent, the interval between the Clarion coals and Lower Kittanning coal is generally occupied by a more or less massive, coarse-grained, pinkish sandstone above 60 feet thick. From considerable portions of the area the softer rocks have been eroded, and the heavy sandstone forms extensive flat uplands, such as those south of Knox, north of Lamartine, and west of Mariasville. Probably only the upper part of this sandstone is equivalent to the Kittanning sandstone member. The towns of Knox (in part) and Lamartine are located on this sandstone. In parts of the area of this sandstone, as, for example, east of Knox, the interval between the Clarion and the Lower Kittanning coal beds is occupied by sandy shale and several thin beds of coal.

Lower Kittanning clay.—The Lower Kittanning clay is generally gray, and varies from 3 to 8 feet in thickness. So far as known, it is everywhere present in this quadrangle. Near Zion Hill and over a large area lying near the northeast corner of the quadrangle a bed of flint clay also is found below the Lower Kittanning coal.

Lower Kittanning coal.—The Lower Kittanning coal lies generally about 35 feet above the Vanport limestone member, but the distance varies from 20 to 50 feet. It is a bed famous for its uniformity and persistency, and is mined throughout the southern half of the quadrangle. Over most of this district it does not vary more than a few inches from 3 feet in thickness. In general, the Lower Kittanning coal thins to the northwest, and is very thin or absent in the large district containing Emlenton, Foxburg, and Parker, and extending eastward to Knox.

In the east-central part of the quadrangle a coal bed about 18 inches in thickness is found below the main Lower Kittanning, and separated from it by 4 to 17 feet of clay. The coal beds diverge to the north, and in the vicinity of Wentlings Corners and Knox there is a coal bed about midway between the Upper Clarion and the Lower Kittanning. Whether this bed should be considered a lower bench of the Lower Kittanning or a separate coal is somewhat uncertain.

Middle Kittanning coal.—Above the Lower Kittanning coal is 35 to 70 feet of shale, including in some places layers of sandstone and sandy shale. The upper strata especially tend to be sandy. The shale shows more or less strong olive tints and is prevailingly soft. Above this member is a coal bed, locally underlain with clay, but more generally it rests upon a nonfissile, sandy mudstone.

The older surveys have assigned three coal beds to the Kittanning, and have designated them Lower, Middle, and Upper Kittanning, named from the type locality at Kittanning, Pa. However, in the southeastern part of the quadrangle there seem to be two Middle Kittanning coal beds. The first is about 45 feet and the second about 70 feet above the Lower Kittanning. Both the Middle Kittanning coal beds are thin, and in many sections one or both are absent. This irregularity is shown on Plate VII (p. 16) by sections 13 to 18, in the vicinity of Rimersburg.

Throughout most of the Foxburg quadrangle the Middle Kittanning coal is about 18 inches thick, and is known as the "18-inch bed," and also as the "cannel," "chance," or "local" coal. The average distance of this bed above the Lower Kittanning is 51 feet. One and one-half miles east of Concord Church the distance is 53 feet; one-half mile west of Bela it is 51 feet; and at Bruin the distance is about 35 feet. In general, the Middle and the Lower Kittanning beds diverge to the east, and between the two the extra bed makes its appearance.

Upper Kittanning coal and clay.—The Upper Kittanning coal, commonly called "Pot vein," or "Stray vein," lies from 130 to 180 feet above the Vanport limestone member. The coal is very irregular in thickness, dip, and quality, and is absent over large areas. The underclay seems to be more persistent than the coal. One-half mile east of Petrolia this coal is from half a foot to 7 feet thick, and dips much more steeply than adjacent strata.

Lower Freeport limestone member, coal, and clay.—Between the Upper Kittanning and the Lower Freeport coal beds there are about 40 to 60 feet of rock, which varies from shale to conglomerate, but is predominantly sandy. This rock is widely known as the Freeport sandstone, but has sometimes been called the "Lower Freeport" sandstone. Northeast of Catfish and elsewhere the sandstone is conglomeratic, containing many pebbles one-fourth inch, and a few 1 inch in diameter.

On Myers Hill, southeast of Sligo, and on Squirrel Hill, fragments of limestone along the roadside indicate local developments of the Lower Freeport limestone member. It is not known to occur elsewhere.

A bed of clay is generally present between the sandstone and the coal. It is gray and averages about 5 feet thick.

The Lower Freeport coal lies from 175 to 220 feet above the Vanport limestone member, and is called "Lost vein" and "Pot vein." It is irregular, but less so than the Upper Kittanning. It is present to a limited extent near the tops of the hills in the southeastern part of the area, and is locally of minable thickness (2 feet or more). It is also mined to a small extent about midway between West Freedom and Rimersburg, where it is known as the "Wilcott vein." In this district it is separated into two benches by a parting of shale 1 to 2 feet thick.

Upper Freeport limestone member and clay.—Above the Lower Freeport coal there is from 30 to 50 feet of sandy shale and sandstone, grading locally into conglomerate. In the north edge of Rimersburg, there is an outcrop of flint clay at the horizon of the Upper Freeport clay. The flint clay, however, is probably of very local development.

Of much wider occurrence, though it is irregular, is the Upper Freeport limestone member, with which is more or less plastic clay. It is present at New Athens and Sandy Hollow and thence north to Concord Church, and locally from Petrolia north to Bear Creek.

Upper Freeport coal.—The Upper Freeport or "Summit" coal lies about 245 feet above the Vanport limestone member. It is a persistent bed, but variable in thickness. In perhaps half the area of its occurrence the overlying strata are of shale, and here the thickness is uniformly 3½ to 5 feet. Elsewhere the coal is overlain with sandstone, and the thickness in such districts varies greatly in short distances.

The stratigraphic position of the Upper Freeport coal is high, and consequently it is found only in those parts of the area where the higher rocks occur. It is almost uninterrupted in the southern half of Foxburg quadrangle, and is mined extensively in the vicinity of Rimersburg, at Petrolia, and in many other localities.

CONEMAUGH FORMATION.

The Conemaugh formation, widely known also as the "Lower Barren Measures," takes its name from Conemaugh River, along which it outcrops in typical form. It extends from the top of the Upper Freeport coal to the base of the Pittsburg coal. It is varied in character, and few of its strata are uniform over any considerable area. Considering the bulk of the formation, the proportionate mass of sandstone and shale is about the same as in the Allegheny, but there is less limestone and much less coal.

The entire thickness of the Conemaugh in this part of the State is over 500 feet. Of this, 230 feet, or nearly one-half, is exposed in the Foxburg quadrangle, the highest rocks being found 2 miles southeast of Petrolia. The formation caps the highest hills, and its distribution is very nearly that of the Upper Freeport coal, just described, for it lies immediately above that bed.

The strata above the Upper Freeport coal vary from olive shale to conglomeratic sandstone. Near Rimersburg the coal is overlain by 70 feet of uniform olive shale, with traces of black shale about 50 feet above the coal. Elsewhere, as at 1 mile east of Lower Hillville, the lowest stratum of the Conemaugh consists of massive sandstone. This is known as the Mahoning sandstone member, from its extensive outcrops along Mahoning Creek. In many places the sandstone is separated from the coal by a few feet of shale, and its upper limit is likewise irregular.

Mahoning coal.—One mile northwest of Queenstown there is a coal bed 1 to 3 feet thick about 45 feet above the Upper Freeport coal, and there is also a "Second Summit Vein" 2 miles southeast of Concord Church. In the last-named place the coal is nearly 3 feet thick, and lies 60 feet above the Upper Freeport. Elsewhere, there is clay and some indication of limestone at this position. The "Second Summit Vein" is correlated with the Mahoning coal, known locally in Pennsylvania, West Virginia, and Ohio, and is discussed in the Report of Progress under the Topographic and Geologic Survey Commission of Pennsylvania, Annual Report for 1907. The coal is generally found between two divisions of the Mahoning sandstone member.

Brush Creek coal.—About 75 to 110 feet above the Upper Freeport coal, or the base of the Conemaugh, is found the Brush Creek coal. The interval between this coal and the Mahoning sandstone is occupied by shale with a yellowish cast. The coal is of little economic importance and is not persistent. The horizon is commonly marked by a peculiar dark shale, and in some sections by a bed of dark blue limestone.

Bakerstown coal.—Above the Brush Creek coal, and separated from it by about 75 feet of sandy, gray shale and thin sandstone, is the Bakerstown coal, so called from Bakerstown, in Allegheny County, where it has been considerably mined. A limestone is found near this coal also.

The highest strata which outcrop in the Foxburg and Clarion quadrangles are sandy, greenish shale; they extend about 75 feet above the horizon of the Bakerstown coal.

QUATERNARY SYSTEM.

PLEISTOCENE SERIES.

After the deposition of the Carboniferous rocks, just described, sediments continued to accumulate for an unknown length of time, but before the end of the Carboniferous period the region was elevated and has remained a land area until the present time. During this long period the surface has been subjected to processes of erosion, and, while the streams carried away much material, they also made local deposits. Of such deposits practically none remain except those made in Quaternary time. These consist of unconsolidated gravel, sand, clay, and silt, and are found along the river valleys at various altitudes up to a little over 300 feet above the streams.

STRUCTURE.

Definition.—By structure is meant the attitude or "lay" of the beds. When first formed, the strata were nearly horizontal, but since that time stresses developed within the earth have tilted, wrinkled, and broken the strata to a greater or less extent. In the eastern part of Pennsylvania this sort of deformation has gone so far that there are only small areas where the strata are horizontal, and faults or places where the rocks are broken and displaced are found in great numbers. But in western Pennsylvania, although the strata have been perceptibly tilted and uplifted hundreds of feet, they have been only slightly wrinkled or folded and very few faults have been discovered. In the Foxburg quadrangle in particular the layers of rock are approximately horizontal. They have a general slope to the south of a few feet to the mile, and this slope is interrupted by low domes, basins, anticlines, synclines, and minor irregularities throughout the area.

Method of representing structure.—Structure is commonly represented in two ways, by cross sections and by contour lines. The former method is better for a region in which the rocks are sharply folded and faulted and the latter for a region where the folds are very low and there is little or no faulting, for in such a case structural features are scarcely perceptible in a cross section.

In representing the structure by means of contours, a reference stratum is chosen which has extensive outcrops and is easily recognized. The altitude and amount and direction of the slope of its surface are determined at as many points as possible, and lines are then drawn on the map in the same manner that topographic contour lines are made, each of which connects points of equal elevation. In the Foxburg quadrangle the reference stratum used is the Vanport limestone member, and the contour interval 10 feet. Thus, on the map (Pl. I) the sinuous lines marked 1050, 1100, 1150, 1200, etc., are contour lines connecting points on the top surface of the Vanport limestone, which lie at the indicated heights (in feet) above sea level. The unmarked lines between have a vertical interval of 10 feet, those between 1050 and 1100 being 1060, 1070, 1080, and 1090. The dip of the limestone is thus 10 feet in the horizontal distance embraced between the contours. In some cases the altitude of the reference stratum was obtained directly in outcrops, mines, or wells, and in other cases it was calculated from observations on other recognizable strata, for the layers of rock are approximately parallel. The average spacing of the rocks was obtained by measurements made at all places where two or more recognizable beds were found in outcrop or in a well or boring. Thus, where a stratum above the reference layer was found, its altitude was determined and the average distance, or the nearest measured distance to the reference layer, was subtracted; where the outcrop of a bed below was found, the average interval was added, thus giving the approximate altitude at which the reference stratum would lie if it were present. An intersection of a surface contour with a structure contour of the same elevation marks a point of outcrop of the Vanport limestone.

In the Foxburg quadrangle two sets of structural contours were drawn; one set on the top of the Vanport limestone, an outcropping bed, and another set on the top of the Third oil sand, which lies from 800 to 1,800 feet below the surface. These two sets of structural contours are of interest because they show the variations which are found to occur in the structure of different strata in the same area. This difference is due to lack of parallelism of the beds caused by uneven distribution of sediments on the sea floor when they were laid down and to unconformities as mentioned under "Stratigraphy."

Although the structure of the oil sands in the Foxburg quadrangle appears to have had little or no effect upon the shape of the oil pools and their places of accumulation, in other quadrangles of the Appalachian region it is one of the important factors of accumulation, and in such areas is therefore of very great economic value. For this reason a brief explanation may well be made of the methods used in constructing a contour map of the deeply buried oil sands.

Method of making a structural map of an oil sand.—In an area where numerous records of deep wells are available the construction of a contour map of the oil sand is quite simple. Elevations above sea level of the mouths of the wells are secured and the distance down to the top of the sand in each well is subtracted from the altitude of the well mouth, thus giving the elevation of the sand with reference to sea level. If tho top of the oil sand should be below sea level in a given quadrangle a datum plane is assumed 1,000 or 2,000 feet below sea level, and the height in each well of the top of the sand above this plane is platted on the base map and contour lines drawn connecting points of equal altitudes as described above.

In areas where deep wells are widely scattered or where few good records are available, the construction of an accurate map of an oil

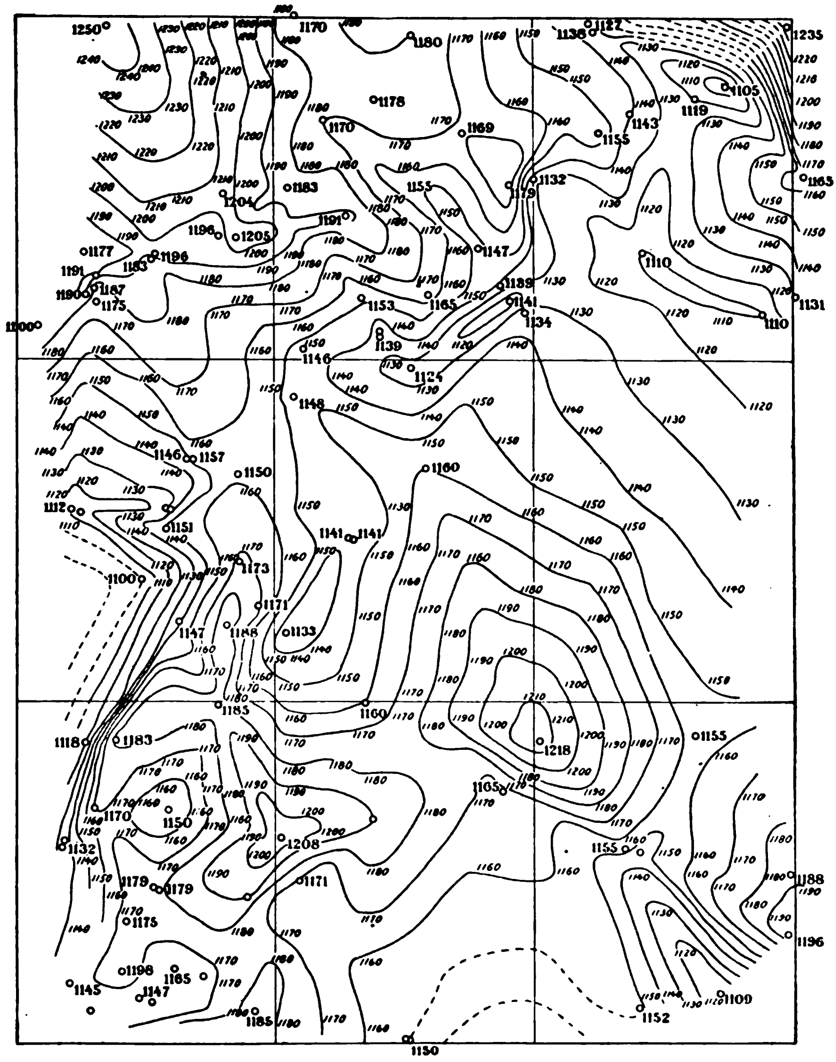

FIGURE 4.—Convergence map showing variation in distance between top of Vanport limestone member and top of Third or Gordon sand.

sand is much more difficult and requires a combination of the material for the two structural maps in such a way that altitudes on the outcropping bed are reduced to equivalent altitudes on the oil sand. This is done geographically by means of the convergence sheet, a brief description of which follows.

Convergence sheet.—The convergence sheet is a mechanical drawing on which are platted lines of equal distance (isochor lines) between the outcropping bed and the oil sand upon which structural contours are to be drawn. To make this drawing, all deep wells at which the distance between the tops of the two beds is known are platted in their proper positions on the base map. (See fig. 4, and note the wells marked by the numbers in larger type.) These wells are connected by straight lines, on which are laid off proportionately the difference in the distance between the tops of the beds as found in the wells thus connected. Points of equal distance are then connected by lines, thus forming the sinuous isochor lines of figure 4. Over this convergence sheet is then laid a transparent tracing of the structural contours of the outcropping stratum, and the altitudes thereon are reduced to equivalent altitudes of the lower bed by subtracting the vertical distance as shown by the lines of the convergence sheet.

In the Foxburg quadrangle an accurate structure map of the Vanport limestone was made by E. W. Shaw in connection with work for a folio of that region. By the use of this structural map and the well-record data obtained M. J. Munn has attempted to make a similar structure map of the Third sand by determining the variation of interval between this limestone and the Third sand and showing it on the convergence sheet, as described above. The difficulty of making an accurate structural map of the oil sands in this quadrangle is due to lack of accurate detailed records of many of the thousands of wells drilled therein and to the fact that in reconnaissance work of the nature done on this quadrangle the altitudes of comparatively few of the wells could be secured.

Variation in the structure of the Vanport limestone member and the Third sand.—From the structure maps it will be noted that if the beds were originally deposited in horizontal layers on the old sea bottom, they have since been slightly tilted to the southeast and wrinkled into a number of very shallow irregular anticlines and synclines. The anticlines or arches are broad and flat, from the axes of which the rocks dip very gently. The synclines or troughs are also flat and very irregular, with a tendency to grow shallower and to disappear toward the north. It will also be seen that the folds appear to be steeper and more pronounced in the Third sand than in the Vanport limestone. This condition is found in all portions of the Appalachian region over which structural work of this character has been done. As may be seen by a comparison of the contours of Plates I and X, the local variations of structure of these two beds are of considerable magnitude, though the general structural features are essentially the same in both.

Use of structure contours.—The structure map is of value not only for the study of broad structural problems and for an abstract knowledge of the structure of the region, but it has a practical value which lies in the aid it may give in locating and recognizing beds of value and in the data it gives concerning the "lay" of such beds. Since the strata of rock are approximately parallel and the average spacing of the valuable beds is given (see sections on pp. 26 and 27), it is not a difficult problem to calculate the approximate position of any bed at any point by adding or subtracting, according as the bed is above or below the key rock, or reference stratum, the average distance between the two to the elevation of the reference stratum as indicated on the map. The map may be used in this way not only for locating coal, clay, and limestone, but for the oil and gas bearing rocks.

In all mining exploitation in stratified rocks it is essential to know the strike and dip of the beds. The importance of this knowledge is well brought out by the hundreds of coal prospects which have been abandoned because the bed was found to dip away from the outcrop. The expense of draining and hauling up the slope to the opening was considered too great to allow of profitable work. In some cases deep ditches have been dug to drain the mine, whereas if the dip of the bed had been known it would have been opened in a more favorable location.

Accuracy of structure contours.—The accuracy of the structure contours depends upon three factors: First, the accuracy of the altitudes obtained directly; second, the difference between the actual and the assumed distance to the key rock as calculated; third, the number and distribution of the points whose altitudes are known. In the Foxburg quadrangle the altitudes were determined with a hand level, and the possible error is thought to average less than 3 feet. The second factor is more likely to cause error, because the different strata are not parallel. The effect of the third factor varies in different areas, but generally in the Foxburg quadrangle points at which the altitudes of well-marked beds have been determined are numerous and well distributed. When all the possibilities of error are allowed for, it is assumed that the structure contours are, for the most part, correct within a contour interval. It is thought that the extreme error is not more than 15 feet and that the average error is less than 5 feet. Certain districts are known to be mapped more nearly correctly than others in which the data are meager and scarcely sufficient to warrant 10-foot contour lines.

Former ideas of structure.—In the report of the Second Geological Survey of Pennsylvania on Clarion and Butler counties[a] Chance describes four anticlines and four synclines crossing the Foxburg quadrangle. They are represented by straight lines drawn approximately N. 35° E. and bear the following names and positions, beginning at the southeast:

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[a] Second Geol. Survey Pennsylvania, Rept. VV, pp. 23-30.

Bradys Bend anticline, in the southeast corner of the quadrangle.

Bradys Bend syncline, just east of Catfish and Callensburg.

Millerstown anticline, passing about 2 miles east of West Monterey, and through Callensburg.

Millerstown syncline, about one-half mile northwest of the anticline.

Martinsburg anticline and syncline, about one-half mile apart, near Fairview and Parker.

Harrisburg anticline and syncline, about one-half mile apart, and passing through Scrubgrass Bend between Wood Hill and Rockland stations.

The present survey, instead of finding numerous straight and narrow parallel folds, worked out a few irregular, broad folds, which are shown in detail on the map (Pl. I). These structural features are the product (1) of irregularities of the surface upon which each layer was deposited; (2) differential settling; (3) warping at various times since deposit. Some features suggest slight folding. Such features are the depression west of Knox, the one between Parker and Emlenton, and the one running north from Petrolia, but the structure as a whole is that of gently sloping surface, with slight irregularities throughout. The general dip is probably the result of deformation since the rocks were laid down, but the irregularities of the northwestern part of the quadrangle are somewhat similar to those represented on coastal charts of such regions as that off Cape Henry or the central part of Chesapeake Bay. It is therefore considered probable that the irregularities of structure are due in part to the shape of the floor upon which each successive stratum was laid down..

COAL BEDS OF THE FOXBURG QUADRANGLE.

By E. W. Shaw.

INTRODUCTION.

Bituminous coal and petroleum are and will for many years continue to be the most important mineral resources of the Foxburg quadrangle. Of these two it is difficult to say which is more valuable, particularly since in 1909 and 1910 the price of oil has been falling, while the price of coal has been gradually rising. In 1908 the production of coal at the ten active shipping mines in this quadrangle amounted to 386,263 short tons.

Although none of the coal beds is everywhere workable on its own merits and many are unworkable throughout extensive areas, it may be that in years to come a considerable part of the coal which is unworkable at present will be mined not only on account of the probable increase in the price of coal, but by reason of the fact that considerable iron ore exists in these rocks, and it may be that a part of the thin coal will sometime be taken out incidentally in iron mining. The iron ore was worked 50 years ago, and with the exhaustion of richer deposits it may be worked again.

Most of the coal beds belong to the Allegheny formation. An estimate of the average total thickness of coal in this region, based on many measurements, indicates that no less than one-fourteenth of the total volume of the formation is made up of this valuable mineral. Four beds are known to be workable over considerable areas. These are the Lower Clarion, Lower Kittanning, Lower Freeport, and Upper Freeport. Openings have also been made on the Mercer, Brookville, Craigsville, Upper Clarion, Middle and Upper Kittanning beds, and also on the Mahoning coal of the Conemaugh formation and the Mercer coal of the Pottsville formation. All of these strata outcrop in the quadrangle, and the coal has been mined almost exclusively by drifting. A small part of the area—that occupied by the river gorges—is not coal bearing. Below the level of the rivers it is all but certain that no coal will ever be found.

On the whole the coals are of good quality, but partly on account of sulphur and other impurities they are of little value for coke. About 1870, however, considerable coke was made from the Upper Freeport coal at Sarah Furnace and Redbank Furnace, near the southern boundary of the quadrangle. The lower coal beds, particularly the Clarion, run high in sulphur, generally containing 3 or 4 per cent or more.

In the field work on the general geology and coals every mile of public highway and every ravine was traversed, and the outcrops were studied and described. It was the aim also to visit every mine, prospect, and quarry in the area. Hundreds of hand level lines were run from benchmarks to recognizable strata, and the topography, both in the field and on the map, was carefully studied in order to gather all the preserved record of past events. Such deformation as has taken place has left the rocks in slightly tilted positions, and an idea of the approximate amount and direction of the dip at any place can generally be gleaned from a study of the present surface, for in a series of alternating hard and soft strata the surface features produced by erosion are closely controlled by the arrangement and altitude of the various beds.

GENERAL DESCRIPTION OF COALS.

Pocono coal.—At a few places thin lenses of shaly coal were found near the top of the Burgoon sandstone. One of these lenses was seen in the river bluff opposite Emlenton. Here the coal is 5 inches thick and has a lateral extent of more than 20 feet. It lies between beds of sandstone and appears to be of very poor quality. The other lenses of Pocono coal seen are less than 3 inches in thickness, and some of them are underlain with clay.

Mercer coal.—The Mercer coal beds are thin and shaly, and consequently of little value. At several places drillers report a bed of black, carbonaceous material, 4 to 8 feet thick, at the position of the Mercer, but no such thickness of coal was seen in outcrop, and it seems probable that the carbonaceous bed is black shale or shaly coal, and not good coal. The Mercer seems to be best developed and the coal beds thickest in a belt extending from Callensburg to Parker, where the coal beds are 2 to 4 in number and range up to 20 inches or more in thickness.

Brookville coal.—The Brookville coal is somewhat thicker than any of the Mercer coal beds, but it is generally too thin to be workable. In many places it is broken up by thick partings, and in some places its sulphur content is large.

At many places the Brookville is divided into several members or benches. The most noteworthy case of this kind is found in the vicinity of Knox, for apparently it is 18 feet from the top of the highest bench to the bottom of the lowest. Other sections to the south show a similar division of the bed, but the partings decrease in thickness and disappear as they are followed south.

Craigsville coal.—With the exception of one or two small areas, the Craigsville coal is of no economic value in this quadrangle. Where seen and recognized it generally ranges from 3 inches to 20 inches in thickness, but southeast of Knox there are several abandoned prospects on this bed in which the coal is reported to have been 3 feet thick. The greatest thickness observed was in the weathered outcrop 1 mile east of Callensburg, where the coal measured 20 inches.

Clarion coal.—The Clarion coal is sulphurous and carries one or more binders, but it is 2 to 7 feet thick, persistent, and the most extensive and valuable bed in the Foxburg quadrangle. It is probable that it underlies the whole quadrangle, except in those places from which it has been removed by erosion, and throughout much of the area it is divided into two benches, the lower of which is generally thicker. The amount of iron pyrite or sulphur which is found in the bed is so large that it serves as an identification character, and the coal is known as the "Sulphur vein."

Lower Kittanning coal.—In the southern half of the quadrangle the most important coal is the Lower Kittanning. It is persistent, uniform in thickness, and widely distributed. No regular partings occur in the coal, and the irregular ones are thin, in few places being over one-half inch thick. In about one-half of the sections measured no partings were noted. In the others, from 6 to 12 inches below the top of the coal occurs a binder of splinty character, from one-half to 2½ inches in thickness, that is readily distinguished on fresh surfaces of the coal. In mining, no attention is paid to this binder. The average thickness of the Lower Kittanning is about 3 feet, but the upper portion generally consists of 2 to 12 inches of bony coal, thus making the average thickness of clean coal 1 or 2 inches under 3 feet. In the northern part of the quadrangle the coal is broken up by partings and over considerable areas is thin or absent. In the vicinity of Emlenton there is scarcely a trace of it.

Wherever seen, the bed has a shale roof and a clay floor. Analysis of the coal generally shows that it is high in sulphur and moderately high in ash, but it contains less sulphur and is known as a more valuable coal than the Clarion. In the vicinity of Wentlings Corners it is unusually free from sulphur and has been used as a blacksmith coal.

The position of this coal bed, like that of others, is such that over the greater part of the region it can be mined by drifting. In the northern third of the area the coal is found in only a few isolated patches and these are now practically worked out, but south of a line drawn through Clarion and Parker the coal is present in nearly all the hills.

In the northeast corner of the Foxburg quadrangle there are two coal beds near the position of the Lower Kittanning, separated by shale and sandstone. The upper one is the more valuable, and it shows very unusual local dips. Near Wentlings Corners there is said to be a drop of 30 feet in a distance of 40 rods.

Much of the coal that is shipped from this quadrangle is taken from the Lower Kittanning bed. It is used as a domestic and steam coal in northwestern Pennsylvania and western New York and a small amount goes to Canada.

Middle Kittanning coal.—In the eastern part of the Foxburg quadrangle there are two coal beds between the Upper and Lower Kittanning. Both of them are thin and not of great value. In the central and southwestern part, the Middle Kittanning is 12 to 30 inches thick, averaging about 16 inches. It is commonly held as a reserve supply by farmers when they sell the Lower Kittanning. There are several small country banks on this coal.

Upper Kittanning coal.—The Upper Kittanning coal is variable in thickness and quality and is worthy of its name "Pot vein." With one or two exceptions, this coal is found only in the southern half of the quadrangle, and in most of the few openings it is thin and dirty. Near Petrolia it is minable, but in one place the thickness in 200 yards decreases from 66 inches to 7 inches.

Lower Freeport coal.—The Lower Freeport coal has been opened in a number of country banks, but it is absent over large areas and where present it is generally too thin to be workable.

About 3 miles southeast of West Freedom the Lower Freeport coal is known as the "Wilcott vein." It is mined here in several country banks and the quality is as usual very good, but there is a parting of shale about 2 feet thick which separates the coal into two benches, each about 2 feet thick.

Upper Freeport coal.—Next to the Lower Kittanning and Clarion coal beds the Upper Freeport is the most valuable in the Foxburg quadrangle. It is quite persistent and is of minable thickness in perhaps half the area in which it occurs. There are no shipping mines on the coal, but in the vicinity of Redbank Furnace, just south of the area, it has been mined extensively for the last fifty years, and much of it has been coked. The coke was not of superior quality but was used in iron smelting. The Upper Freeport is found near the tops of the hills, consequently it occurs in many isolated areas, and its outcrop is long and irregular. It is extensively worked in the vicinity of Rimersburg and also near Fairview.

Coal beds above the Upper Freeport coal.—The Mahoning coal is found in a few small areas in this quadrangle. It has been prospected near Queenstown and also 3 miles southeast of West Freedom, where it is known as the "Second Summit vein." The coal lies under slight cover and scarcely reaches workable thickness. It is, however, reported to be of very good quality.

The Brush Creek and Bakerstown coals occur in only a few small areas, and are less than 12 inches thick.

COAL ANALYSES.

No samples of coal were collected in the Foxburg quadrangle, but the following analyses of coal from the adjoining quadrangle to the east indicate the general character of the coal:

Analyses of coal samples from Clarion quadrangle, Pennsylvania.[a]

	Upper Freeport.		Lower Freeport.	Upper Kittanning.		Lower Kittanning.				Clarion.	Craigsville.
Laboratory No.	4111.	4171.	4172.	4176.	4177.	4116.	4170.	4055.	3951.	4173.	3953.
Analysis of sample as received:											
Moisture	3.98	5.56	3.30	5.89	4.09	2.87	2.73	4.09	3.36	4.84	2.35
Volatile matter	33.70	30.72	33.79	30.46	30.24	34.51	34.77	34.79	35.94	37.86	37.47
Fixed carbon	54.50	57.14	56.83	48.66	57.37	54.31	52.20	55.32	52.05	50.28	49.01
Ash	7.82	6.58	6.08	14.99	8.30	8.31	10.30	5.80	8.65	7.02	11.17
Sulphur	2.18	1.10	2.73	1.60	1.01	1.36	3.66	2.39	2.30	3.98	4.04
Loss of moisture on air drying	2.30	3.30	1.80	3.90	2.10	1.00	1.30	2.60	1.70	3.20	1.10
Analysis of air-dried sample:											
Moisture	1.72	2.34	1.53	2.07	2.03	1.89	1.45	1.53	1.69	1.69	1.26
Volatile matter	34.49	31.76	34.41	31.70	30.89	34.86	35.23	35.72	36.56	39.11	37.89
Fixed carbon	55.79	59.09	57.87	50.63	58.60	54.86	52.89	56.80	52.95	51.95	49.56
Ash	8.00	6.81	6.19	15.60	8.48	8.39	10.43	5.95	8.80	7.25	11.29
Sulphur	2.23	1.13	2.78	1.66	1.03	1.37	3.71	2.45	2.43	4.11	4.08

[a] Lines, E. F., Coals of the Clarion quadrangle, Pennsylvania: Bull. U. S. Geol. Survey No. 316, 1907, pp. 13-19.

4111. Saylor country bank, 2 miles south of Sligo.
4171. Fairmount No. 11 mine, 3 miles northeast of New Bethlehem.
4172. Fairmount No. 12 mine, 3 miles northeast of New Bethlehem.
4176. John Mohney country bank, 5 miles southeast of Sligo.
4177. Sam Shankle country bank, 1 mile northwest of New Bethlehem.
4116. Baldorf No. 1 mine, 2 miles southeast of Strattonville.
4170. Mine No. 1, 1 mile north of Oak Ridge.
4055. Acme Mine, 1 mile south of Rimersburg station.
3951. Lyon Shorb country bank, at Sligo.
4173. George Cook country bank, 1½ miles northwest of Clarion.
3953. Sligo Mine, at Sligo.

DETAILED DESCRIPTION OF COALS.

In order to facilitate the detailed description of the coals, the quadrangle will be divided into three districts—(1) that lying east of the Allegheny and north of the Clarion, (2) that lying east of the Allegheny and south of the Clarion, and (3) that lying west of the Allegheny.

COAL BEDS IN DISTRICT EAST OF ALLEGHENY RIVER AND NORTH OF CLARION RIVER.

General conditions.—In the northern part of the quadrangle, the base of the Allegheny formation lies well up in the hills and the upper part has been removed by erosion. Consequently the number of coals found here are few, those which anywhere exceed 1 foot in thickness being the Mercer, Brookville, Craigsville, Lower and Upper Clarion, and Lower and Upper Kittanning. From that part of the district occupied by the deeper valleys, an area amounting altogether to several square miles, all of these coal beds have been removed by erosion. Moreover, as they are followed north the coal beds generally show a tendency to split and become shaly. The sections given in Plate VI (p. 16) were measured and drawn from roadside and ravine exposures and illustrate the stratigraphy of this district.

The general southward dip of the rocks is modified by a broad depression between Lamartine and Knox, another at Allegheny River, and numerous small irregularities throughout the district.

Figure 5 shows representative sections of the Mercer, Brookville, and Craigsville coals.

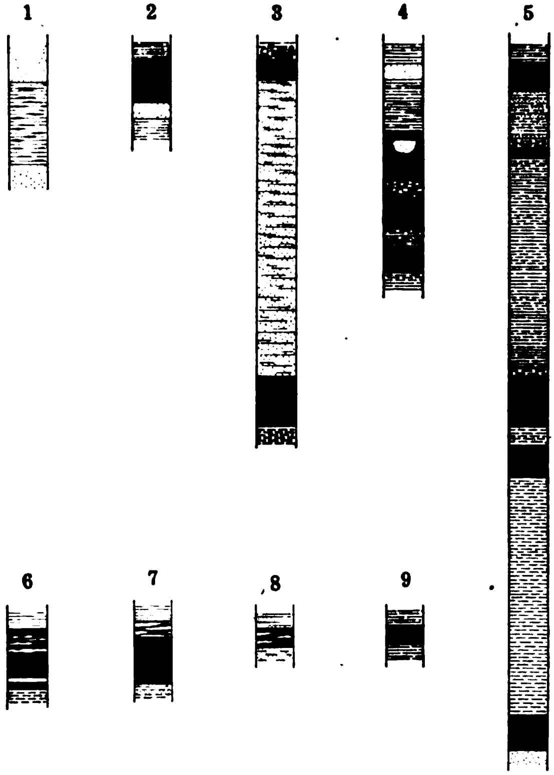


FIGURE 5.—Sections of Mercer, Brookville, and Craigsville coals in the northern part of the Foxburg quadrangle. Scale, 1 inch=5 feet.

Mercer coal: (1) 2 miles southeast of Emlenton.

Brookville coal: (2) 3 miles north of Callensburg. (3) Blairs Corners. (4) 1 mile southeast of Blairs Corners. (5) One-half mile east of Knox. (6) 1 mile southeast of Emlenton. (7) 1 mile west of St. Petersburg.

Craigsville coal: (8) 1 mile southwest of Lamartine. (9) 1½ miles southeast of Emlenton.

Mercer coal.—One or more Mercer coal beds outcrop here and there in this part of the quadrangle, but they are nowhere workable. The thickest coal seems to lie about 2 miles southeast of Emlenton, where about 16 inches of shaly coal were seen in the river bluff. In one place this coal lies between heavy beds of sandstone, but a short distance away what appears to be the same bed is overlain with shale and underlain with clay. Elsewhere in the district the Mercer coal beds seem to be only a few inches thick.

The structural geology map (Pl. I) shows that north of Clarion River the top of the Vanport limestone member lies for the most part over 1,300 feet above sea. Since the Mercer coal beds lie less than 200 feet below the Vanport limestone, their altitude ranging from 1,100 feet up, or fairly high in the hills, and since these beds are the lowest which may contain workable coal, it follows that coal prospecting in the valleys, either at the surface or by deep drilling, would be time and energy wasted. Only very thin seams of coal have ever been found in this region below the Mercer.

Brookville coal.—The Brookville coal seems to be the most persistent coal in the district, but, except for places where it is broken up by thick partings, it does not attain a thickness of more than 2 feet. In the vicinity of Emlenton the coal ranges from 10 to 22 inches in thickness, and has been opened for mining in the river bluff, 2 miles southeast of Emlenton. Eastward the bed separates into 2 or more benches, which diverge toward Knox, where there are no less than 5 benches of Brookville coal, separated by layers of sandy to shaly clay. The total thickness of these benches is over 4 feet.

Generally the Brookville coal is of excellent quality and is very low in sulphur. In many places it has been stripped and mined in very small quantities for use as a blacksmith coal. A part of the stratum is locally a more or less pure cannel coal, which varies to a shale, with a cannel-like appearance. Another characteristic of the coal is that lenses of sandstone are commonly included in it or interbedded with its benches. Most of these lenses are only a few feet in horizontal extent, and are cemented with iron and calcium carbonates into a very hard rock.

With few exceptions the coal is overlain by soft shale several feet thick and containing "ore balls" of iron. In a mine this shale would break and fall very easily. The floor of the coal varies from soft clay to a hard white sandy clay, which because of its resemblance to both fire clay and sandstone has sometimes been spoken of as a "fire sandstone."

Craigsville coal.—The Craigsville coal is not a very persistent bed and is not minable at present anywhere in the northern part of the Foxburg quadrangle. The coal bed is thin and broken up by partings of carbonaceous shale. It is doubtful whether it will ever be mined. Not more than 6 inches of good coal were found in any outcrop of this bed. One peculiarity of the Craigsville is that in only a few places is it underlain with clay. Generally, it lies between layers of iron-bearing shale.

Clarion coal.—Throughout the district lying north of Clarion River the Clarion coal is separated into two persistent beds, the interval being filled with shale or clay and in a few places sandstone. Both coal beds are generally workable, though they have a high sulphur content, the lower one in particular containing throughout its extent a large amount of iron sulphide, generally in the form of marcasite and being for this reason known as the "Sulphur vein." Coal from the lower bed is said also to leave more ashes and clinkers than that from the upper.

But, notwithstanding their impurities, the Clarion coals are by far the most valuable in the district; indeed, they are the only coal beds that have been worked to any extent. The lower bed is commonly spoken of as the "Four-foot vein," and the upper as the "Three-foot vein," though the average thickness is slightly less than these figures would indicate. The lower bed ranges from 20 inches to 50 inches and the upper generally from 8 inches to 38 inches, but at St. Petersburg the upper bed is thicker, reaching 58 inches in the Richland Coal Company's mine. Figure 6 shows typical sections of both branches of the Clarion coal.

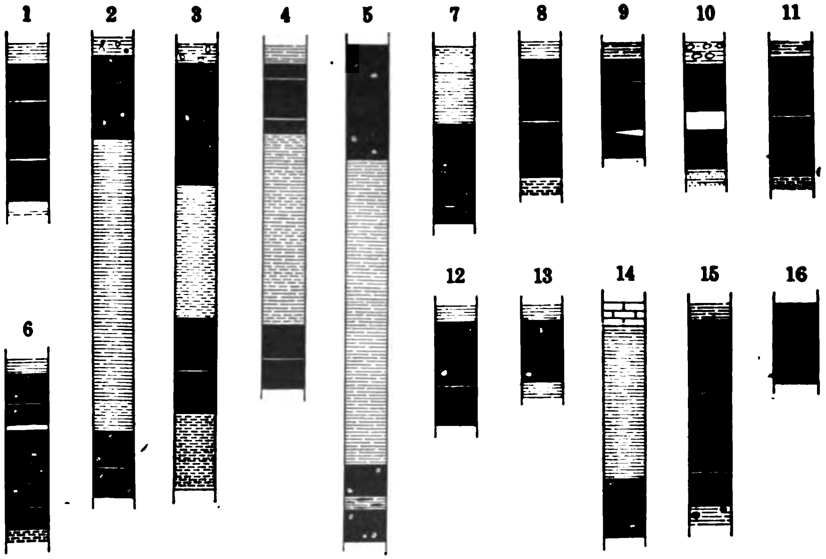


FIGURE 6.—Sections of Clarion coal. Scale, 1 inch = 5 feet.

Upper and Lower Clarion coal: (1) 1 mile northeast of Emlenton. (2) 3 miles east of Emlenton. (3) Eastern part of St. Petersburg. (4) One-half mile east of Richmond. (5) 2 miles southeast of Knox. Lower Clarion coal: (6) Russell's mine, 2½ miles southeast of Emlenton. (7) 1 mile northeast of Emlenton. (8) 3½ miles northeast of Emlenton. (9) 1 mile west of Lamartine. (10) 3 miles west of Knox. (11) 2½ miles southwest of Knox. (12) 1½ miles southeast of Wentlings Corners. (13) 1 mile northeast of Emlenton. (14) 2 miles north of Dotter's station. (15) Richland Coal Co.'s mine, St. Petersburg. (16) 1 mile northwest of Turnip Hole.

The Lower Clarion coal has a persistent binder one-fourth inch to 6 inches thick near the middle of the bed, and in many places contains one or more additional binders. It lies upon a thick bed of soft clay, which in many places at least is worth working. The coal is overlain by a shale, which is more or less carbonaceous and makes a fairly strong roof. At present, there are no shipping mines on the Lower Clarion, but there are scores of country banks from which coal is taken for local domestic and steam use.

The Upper Clarion coal has no regular partings, but contains local thin lenses of bone and shale. Sulphur balls are numerous, both in the coal and in the roof and floor. Throughout much of its extent the coal lies between beds of shale. The floor, however, is inclined to be clayey, and in one or two places a bed of soft white clay was seen underneath the coal.

The only shipping mine on this bed is at St. Petersburg, where the coal ranges from 40 to 58 inches in thickness. Here the roof and floor are both hard but brittle, the material being a compact mudstone with concretions and nodules of marcasite and very uneven stratifications. The coal has been opened at many other places, but has not been worked extensively because of the proximity of the lower thicker and more attractive bench of the Clarion.

The Clarion coals underlie about 50 square miles, or two-thirds of the district, and have been mined out from perhaps 10 square miles. A considerable part of the mining has been wasteful, not more than a third of the coal being taken out. Thus, the coal has been "hogged out," as the miners say, and many small bodies of good coal are lost among the old workings.

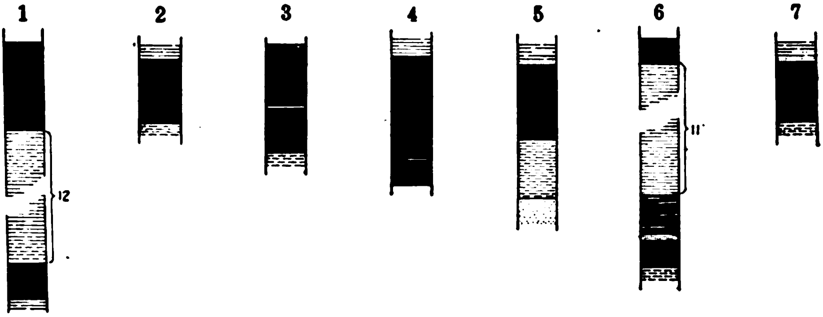


FIGURE 7.—Sections of Lower Kittanning coal. Scale, 1 inch=5 feet.

(1) One-half mile south of Keefer Mill. (2) One-half mile east of Richmond. (3) 1½ miles northeast of Turnip Hole. (4) One-half mile north of Wentlings Corners. (5) One-half mile south of Wentlings Corners. (6) 3 miles north of Callensburg.

Lower division of Lower Kittanning coal: (7) One-half mile northwest of Lamartine.

Lower Kittanning coal.—The Lower Kittanning coal, which is so valuable over an area extending south and southwest for hundreds of miles, is almost worthless in this district. In many localities it could not be found, and only here and there is it workable. Throughout the northern two-thirds of the district its horizon is found only in the tops of the hills, and it is absent from the broad valleys which occupy much of this area. Where seen and recognized it is probably somewhat thicker than elsewhere, so that the sections given in figure 7 probably indicate a better coal than the average. The strata overlying the coal are of gray shale or sandy shale, making an excellent roof, though commonly separated from the coal by a few inches of black "draw slate." The underlying stratum or floor is a firm gray clay.

The coal is present in the hill south of Keefer Mill and locally in the vicinity of Lamartine. It seems to be absent from much territory about Emlenton, Mariasville, and St. Petersburg. Near Richmond several prospects have been opened on it, but, on account of its thinness, the coal was not worked. It has also been opened in a few places near Turnip Hole. In the vicinity of Monroe the coal is broken up by partings of clay. Here the aggregate thickness of the Lower Kittanning coal reaches a maximum of 4 feet or more, but the bed is split into several benches, the highest being 10 to 15 feet from the lowest.

The most valuable coal is found at Wentlings Corners. Here the bed is thick and persistent throughout the broad flat-topped ridge which lies between Beaver and Canoe Creeks. The coal is of excellent quality and has a good roof and floor. It has been mined to a considerable extent and much has been used as blacksmith coal, some for this purpose having been hauled by wagon to places 50 miles away. Considerable difficulty is experienced in mining this coal at Wentlings Corners owing to strong local dips—an unusual feature for the Lower Kittanning coal, which elsewhere lies nearly flat.

Coal beds above the Lower Kittanning.—Coal blooms at or near the horizon of the Middle Kittanning were found here and there, but nowhere were there indications of more than 1 foot of coal. At several good exposures of associated beds, including clay, no coal could be found, and it seems probable that the Middle Kittanning is not at all persistent.

The Upper Kittanning coal is well developed in the hill 1 to 2 miles north of St. Petersburg, where it lies at an altitude of about 1,500 feet. Several years ago it was prospected at one or two places, but not much coal was taken out. Elsewhere in the district the Upper Kittanning seems to be thin or absent.

The Lower Freeport coal was not seen north of Clarion River, though a few of the hills are high enough to contain it. The hills which extend highest in the stratigraphic column are the one about midway between Emlenton and Turkey City, which extends 230 feet above the Vanport limestone member, and the one just north of Monroe, which extends 215 feet above the limestone.

COAL BEDS IN DISTRICT EAST OF ALLEGHENY RIVER AND SOUTH OF CLARION RIVER.

General conditions.—In the southeastern part of the quadrangle, the rocks which outcrop comprise a section extending from the lower part of the Burgoon sandstone to 100 feet above the top of the Allegheny formation. The lowest strata are exposed in the bottom of the

Allegheny Valley at the mouth of the Clarion and the highest form the top of the hill 1 mile east of Catfish. Thus, all of the Pottsville and the Allegheny and the lower part of the Conemaugh are included—a series of strata as richly coal-bearing as any other of similar thickness in western Pennsylvania. The road sections given on Plate VII illustrate the stratigraphy of this district.

In the northern part of the district the rocks dip south at the rate of 20 to 40 feet per mile. Southeast of Freedom and northwest of Rimersburg are areas comprising several square miles each where the rocks have almost no dip. Extending southward from Perryville is a depression of peculiar form, being 8 or 10 miles long and only a mile or two wide. The Rimersburg anticline, which is a well-defined feature of the area to the east, fades out west of Rimersburg and at the river it is imperceptible. With one exception, near Bruin, the steepest dips in the quadrangle are along the southern border east of Allegheny River. Here the strata descend to the south at the rate of nearly 100 feet per mile into a depression known as the Bradys Bend syncline, which lies just off the southern boundary of the quadrangle.

Coal beds below the Clarion coal.—The Mercer coal beds underlie almost the whole district, and outcrop along the bluffs of both Clarion and Allegheny rivers. However, coal is found in but few places, and where seen is thin and dirty. Back from the narrow river valleys not much is known concerning the Mercer coal, for there are no exposures and little careful drilling has been done. In several oil-well records drillers report beds of coal 2 to 6 feet thick at the position of the Mercer; but in ordinary methods of drilling for oil it is not easy to distinguish between coal and black shale. Near Callensburg in particular, beds of black carbonaceous material probably belonging to the Mercer were encountered in several oil wells. It may be, therefore, that lenses of Mercer coal of good quality underlie a part of the area, but, since no good coal measuring more than 9 inches in thickness was seen in outcrop, it seems improbable that any considerable body of minable Mercer coal will ever be found here.

The Brookville coal also is believed to be unminable in this district. Signs of coal were seen at almost every place where the lower part of the Allegheny formation was exposed, but in most places the coal is less than 1 foot thick and in many exposures the coal is broken up by partings of clay, shale, and sandstone.

The Craigsville coal is worthless throughout much of the district, but in the southeastern and northeastern parts it is thick and of good quality. It may be that it will be found to be minable in other parts also, where it is deeply buried under higher strata. In a small country bank in the extreme southeast corner of the area the Craigsville is 28 inches to 36 inches thick, but in a near-by outcrop it was found to be only 9 inches thick. Hence, it is probable that the thickness is irregular and that the coal only locally attains such a thickness and quality as to be valuable. At Sligo, just outside the district on the east side, there is a shipping mine on a coal bed which seems to be the Craigsville, though the correlation is somewhat doubtful. A short distance to the west the Craigsville appears in outcrops in the road, where it ranges up to 20 inches in thickness and appears to be of good quality, containing less sulphur than the Clarion coal.

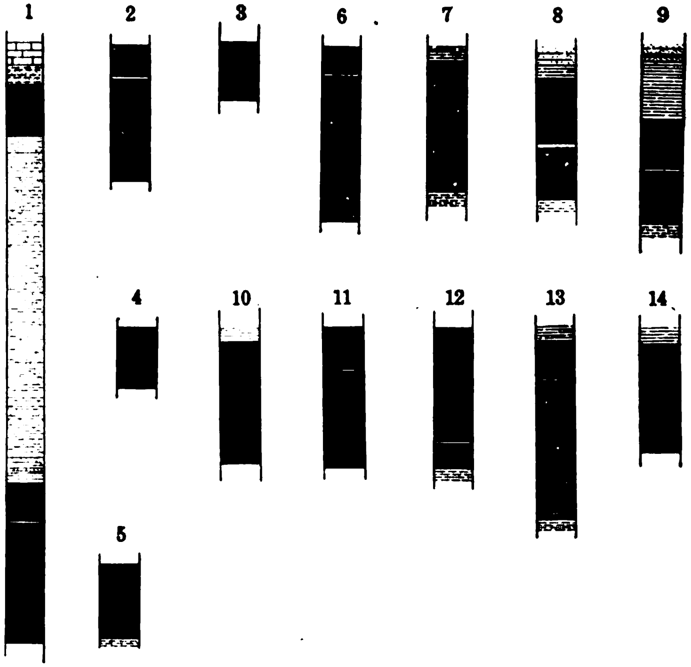


FIGURE 8.—Sections of Clarion and Craigsville coals in southeast part of the Foxburg quadrangle. Scale, 1 inch=5 feet.

Clarion coals: (1) 2 miles north of West Freedom.

Upper Clarion coal: (2) 1 mile north of Parker station. (3) 2 miles east of West Freedom. (4) One-half mile southeast of Callensburg. (5) 1¼ miles east of Callensburg.

Lower Clarion coal: (6) 1 mile north of Parker station. (7) 1½ miles southeast of Perryville. (8) Preston Coal Co.'s mine, at West Monterey. (9) Hicks Coal Co.'s mine, 1 mile southeast of West Monterey. (10) 1 mile west of West Freedom. (11) 2 miles east of West Freedom. (12) 1¼ miles east of Callensburg. (13) 2½ miles southeast of Callensburg.

Craigsville coal: (14) Southeast corner of the quadrangle.

Clarion coal.—The Clarion coal—one of the most valuable in the area—outcrops along the Allegheny River bluffs, and for a mile or two up the tributary streams. It is found also along the side of the valley of the Clarion and up its tributaries for 3 or 4 miles. The outcrop is thus not very long or devious.

As in the northern districts, the coal is separated into three divisions each of which is minable throughout most of the area. The sections (fig. 8) illustrate the thickness of the bed, its partings, and its relations to other strata.

The Lower Clarion coal is persistent and minable throughout its extent. With the exception of a small area from which it has been removed by erosion, it underlies the whole district and is not known to fall below 20 inches in thickness. Generally, it ranges from 30 to 50 inches, but falls below 30 inches along the southern border. The coal lies about 1,250 feet above sea along Clarion River and slopes from this down to about 1,100 feet at the south side of the district. The amount of cover varies from place to place, the greatest depth of the coal below the surface being 340 feet at certain points near Catfish and Rimersburg.

This coal has much sulphur and one or more partings of soft clay, shale, or bone, but, aside from these, the coal is of excellent quality. The bed rests upon a stratum of clay, which appears to be worth working. The clay makes a good floor, but shows a slight tendency to heave. The roof of the coal is, for the most part, a good tough shale, though in a few places the overlying bed is sandstone. There are two shipping mines near West Monterey and the coal has been worked also in many country banks and prospects.

The Upper Clarion coal is fairly persistent and is found throughout most of the territory underlain by the Lower Clarion coal. Its outcrop is not long or complicated, but follows along the sides of the river valleys slightly above the lower division. Generally the coals are so near each other and the hillsides so steep that they could not be mapped separately, though in few if any places are they near enough to each other to be mined together. Along the Allegheny the distance between them ranges up to 30 feet, but along the Clarion the coals are only 5 to 15 feet apart. The intervening stratum is clay shale for the most part, and not rich in iron. Between West Freedom and St. Petersburg a heavy sandstone seems to rise up through and take the place of the Clarion and Craigsville coals and the Vanport limestone member.

The Upper Clarion coal contains less sulphur than the Lower Clarion and has fewer partings and other impurities, but, notwithstanding its superior quality, it is not mined extensively because of its thinness. Generally it does not measure over 24 inches, though locally it thickens up to 40 or 45 inches. For a time there was a shipping mine on this coal, the Pollock Lime and Coal Co. mine, about a mile north of Perryville, but this mine has not been in operation recently. In the vicinity of this mine the Upper Clarion coal is nearly 40 inches thick and apparently of very good quality. Here the overlying stratum is a tough, sandy mudstone, which should make an excellent roof. The material under the coal is a thick bed of soft fire clay. Elsewhere the roof is of shale and the floor of clay or shale.

Lower Kittanning coal.—The Lower Kittanning coal is more widely developed and thicker in this district than in any other part of the Foxburg quadrangle. Its outcrop is roughly parallel to that of the lower coal beds, but slightly longer, for it lies higher and hence extends farther up the tributary streams. It extends up Catfish Run to Kissingers Mill, up Black Fox Run to the Eagle mine, recedes from the river near Church Hill, and follows the wall of the old valley of the Allegheny around Perryville; thence the outcrop swings south to West Freedom, where it crosses a small stream, and from this place runs north and east, winding around the hills toward Callensburg. It is found above drainage along Cherry Run as far as Huey and up Licking Creek to the east boundary of the area. From Licking Creek the outcrop passes northeast through Zion Hill and leaves the quadrangle not quite in the place where Clarion River enters.

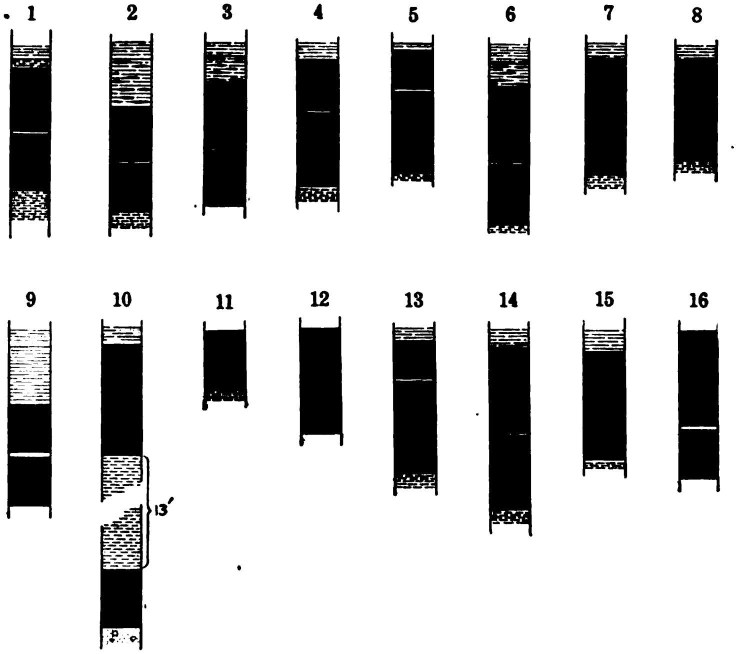


Figure 9.—Sections of Lower Kittanning coal. Scale, 1 inch=5 feet.

(1) Dutch Hill mine. (2) Hillville ("Blue Goose") mine. (3) Eagle mine. (4) One-half mile east of Upper Hillville station. (5) 1 mile north of Catfish. (6) Catfish mine. (7) One-half mile southeast of Catfish. (8) 2 miles east of West Freedom. (9) 1½ miles southeast of West Freedom. (10) One-half mile north of Zion Hill. (11) 1½ miles southeast of Callensburg. (12) 1 mile southwest of Zion Hill. (13) Clarion mine, near Huey. (14) Cherry mine, near Huey. (15) 1 mile northwest of Mount Airy. (16) Southeast corner of quadrangle.

The character of this coal and that of the overlying and underlying strata as well are nearly uniform throughout the district. (See fig. 9.)

The coal is about 3 feet thick in the southern part of the area and thins to 2 feet along Clarion River. One fairly persistent binder lies about a foot below the top of the bed and there are in some places other impurities. The coal has less sulphur than either of the Clarion coals and is known locally as one of the best coals in the region. The overlying strata are of tough gray shale, which in mines makes an excellent roof. The underclay is rather soft, and in wide rooms is likely to heave, but with ordinary care it makes no trouble. Generally this clay is valuable and may be mined to advantage in connection with the coal. In the district there are eight shipping mines on the Lower Kittanning coal, one of which has, however, not been in operation recently. The active mines are the Cherry Run and the Clarion near Huey; the Dutch Hill, Eagle, and Hillville mines, not far from West Monterey; and the Sarah Furnace and Catfish mines, near Catfish.

Two and a half miles northeast of Callensburg there is a local lens of flint clay below the Lower Kittanning coal, which is here separated into two divisions 16 feet apart. The interval is filled with fire clay and a small amount of shale and iron ore. The ore was formerly worked, the clay appears to be valuable, and the coal benches measure 17 inches and 5 inches, so that here the Lower Kittanning and associated beds seem to be of unusual value.

Middle Kittanning coal.—The Middle Kittanning coal is of little value in this district, in few places exceeding 16 inches in thickness, though it is commonly known as the 18-inch bed. It is not a persistent coal, and where present it is commonly only a few inches thick. The average distance between this coal and the Lower Kittanning is about 50 feet, but in this district the distance increases from about 55 feet in the southwestern corner to about 90 feet at Rimersburg, and a short distance north of Rimersburg another coal bed is found about 50 feet above the Lower Kittanning. In the area to the east also there are two coal beds between the Upper and the Lower Kittanning, so there seems to be good evidence of two Middle Kittanning coal beds. The thickest coal seen was at Mount Airy, where there are two benches separated by 18 inches of shale. The lower bench is 4½ inches and the upper 21 inches thick. At this point the strata above the coal consist of 4½ feet of shale overlain by heavy sandstone. Under the coal there is a bed of fire clay 6 feet 9 inches thick, followed by shale and sandstone.

Upper Kittanning coal.—The Upper Kittanning coal or "Pot vein" is present in only a few localities and is very irregular in thickness and quality. Even where best developed the thickness is variable, dropping in a few yards from 4 feet to a few inches. It may be minable in an area of 2 or 3 square miles east of West Freedom and in another area of about the same size north of New Athens. Sections of the coal bed in these localities are shown in figure 10.

Lower Freeport coal.—The Lower Freeport coal is somewhat more extensive and regular than the Upper Freeport, but on account of its thinness and large partings its minable area is no greater. About midway between Rimersburg and Parkers Landing, or one-half to 3 miles northeast of the Eagle mine, the Lower Freeport coal is separated by a shale parting, 1 to 2 feet thick, into two benches, ranging from 12 to 36 inches thick. (See sections 7 and 8 of fig. 10.) In this area it has been mined to a small extent. The roof here is of shale, the floor of soft clay, and the coal seems to be of very good quality. Elsewhere the coal is for the most part not over 1 foot thick.

Upper Freeport coal.—The Upper Freeport coal lies so high that, except on hilltops in the southern part of the district, it has been completely eroded away. Three hills near West Freedom are high enough to contain it; it is found in several hills near Concord Church; and it underlies a considerable part of the country between Rimersburg and the river. Thus there are many isolated areas of Upper Freeport coal, the largest of which is but little over 1 square mile in extent. The total area underlain by the coal is about 12 square miles, or less than one-sixth of the area of the district.

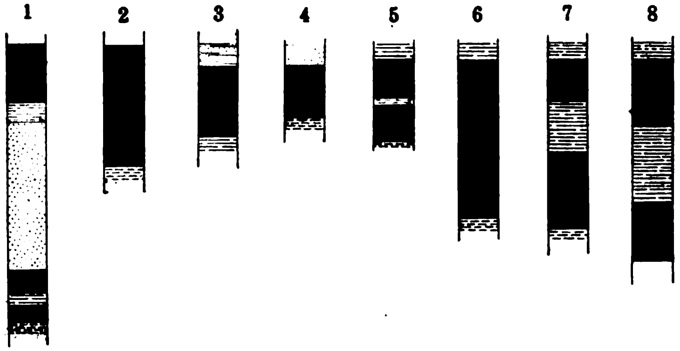


FIGURE 10.—Sections of Middle and Upper Kittanning and Lower Freeport coals. Scale, 1 inch = 5 feet.

Middle Kittanning coal: (1) 1 mile south of West Freedom. (2) One-half mile west of Sligo. (3) 3½ miles north of Rimersburg. (4) 1 mile north of Rimersburg.

Upper Kittanning coal: (5) 1 mile east of West Freedom. (6) 1 mile northeast of New Athens.

Lower Freeport coal: (7) 1 mile north of Eagle mine. (8) 2½ miles northeast of Eagle mine.

The Upper Freeport coal contains less sulphur and other impurities than any other minable coal in the region. Near Catfish it was coked extensively between 1850 and 1870. The coke was of fair quality and was used in the iron furnaces. There are no shipping mines on this coal, but there are many country banks, particularly near Rimersburg, where the coal is thick (see fig. 10) and of a uniform and excellent quality.

Throughout its extent the coal bed rests upon a stratum of fire clay, which overlies or is interbedded with limestone. The strata overlying the coal are more variable, ranging from coarse sandstone to a shale having almost no grit. In mines where the roof is of sandstone the coal is extremely variable in thickness, and the maximum is less than that of the coal where it lies under shale. Thus at Rimersburg, where the overlying stratum is shale, the coal has a comparatively uniform thickness of 4 to 5 feet and has also a bench of bony coal above and below, which grades locally into pure coal; but between Kissingers Mill and Fredell post office the Upper Freeport lies under a heavy sandstone and the thickness ranges in short distances from a few inches to about 4 feet. In one country bank, where sections 3 and 4, figure 11, were measured, the thickness of the coal increases from 18 inches to 49 inches within a horizontal distance of 20 feet. In the local "kitchens," as they are called by the miners, where the coal is thick, the roof, floor, and other features to be considered in mining are almost ideal, but the sandstone is very resistant, and where the coal is thin the necessary rock blasting makes the expense of mining almost prohibitive.

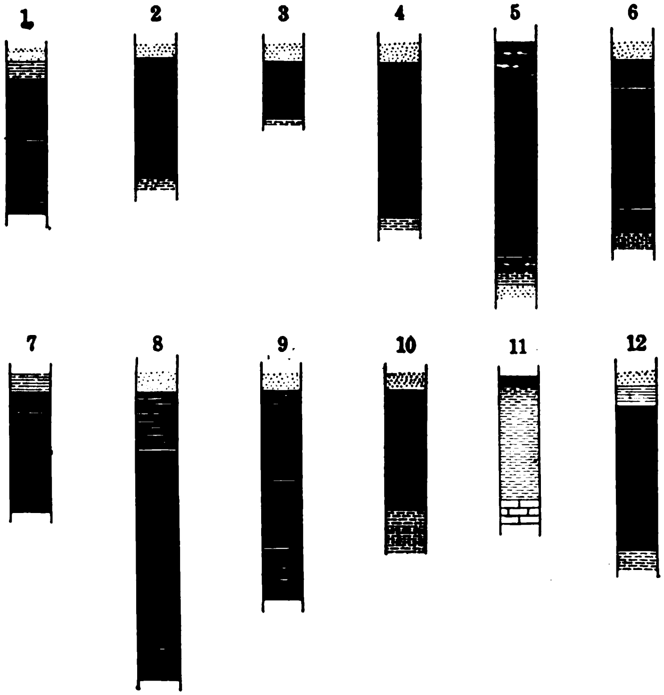


FIGURE 11.—Sections of Upper Freeport coal. Scale, 1 inch = 5 feet.

(1) 1 mile northeast of Dutch Hill. (2) 2½ miles northeast of Eagle mine. (3) 1 mile northwest of Kissingers Mill. (4) 1 mile northwest of Kissingers Mill, 20 feet from section 3. (5) 1½ miles northwest of Rimersburg. (6) 2 miles west of Rimersburg. (7) One-half mile south of Rimersburg. (8) 1 mile southwest of Maple Grove. (9) One-half mile northeast of New Athens. (10) New Athens. (11) Three-fourths of a mile north of New Athens. (12) Sandy Hollow.

Mahoning coal.—The Mahoning coal or "Second Summit vein" is found in the tops of one or two hills 2 miles southeast of Concord Church, but it lies so near the surface that it has been deeply weathered and is not minable. Two or three prospects have been opened on this coal, and it is reported to be about 3 feet thick.

COAL BEDS IN DISTRICT WEST OF ALLEGHENY RIVER.

General conditions.—The highest and the lowest strata of the Foxburg quadrangle outcrop on the west side of Allegheny River. The Meadville shale member of the Cuyahoga formation appears in the bank of the river in the north end of Scrubgrass Township, Venango County, and rocks belonging near the middle of the Conemaugh form the top of a hill a mile and a half southeast of Petroleum. The stratigraphic column for this district thus includes all the coal beds found in the quadrangle. The succession and character of the strata are shown in the road sections given on Plate VIII.

At the north end of the district the rocks dip southeast at the rate of 30 or 40 feet to the mile; between Emlenton and Parkers Landing this dip is modified by a north-south depression, 50 to 100 feet deep; and in the southern half of the district the rocks have an irregular attitude. A slight syncline lies under Petrolia and Bruin; another runs from a mile east of Fredericksburg to West Monterey, and a third underlies Queenstown and Fredell.

Coal beds below the Clarion coal.—The strata below the Clarion coals underlie all but a small fraction of the district and outcrop along the gorge of the Allegheny, and for short distances up each side of the tributary streams. But none of the beds of coal are at present workable. A shaly Mercer coal measures 17 inches at Parker, but elsewhere the Mercer, Brookville, and Craigsville are less than 1 foot thick wherever seen. However, exposures of these coals are not abundant, and it may be that each of them attains local thicknesses of 20 inches or more.

Clarion coal.—Throughout most of the district the Clarion coal is separated into two divisions, but in the southwest corner there is a single bed with a parting of clay shale which seems to be equivalent to the strata which lie between the Upper and the Lower Clarion coals in other parts of the Foxburg quadrangle.

The Lower Clarion coal outcrops extensively and underlies a large part of the district. Its most northern exposure is in the hills 2½ miles northwest of Emlenton and 1 mile south of Wood Hill station. From this point the line of outcrop winds around the hills running up one side of each valley and back along the other side. For a considerable distance in Sugar Valley the coal is not exposed and is doubtfully present. From Sugar Valley south the line of outcrop is somewhat devious but lies within a mile or so of the river, to a point opposite the mouth of Clarion River. Here it inclines to the west and follows the western side of an old valley of the Allegheny as far as Bear Creek. The coal lies above drainage along both sides of north and west branches of Bear Creek and passes below South Branch one-half mile south of Bruin. Southeast of Bear Creek the tributaries of the Allegheny are small, the valley side is steep, and the position of the coal is low. The outcrop therefore lies close to the river, extending less than a mile up the tributaries.

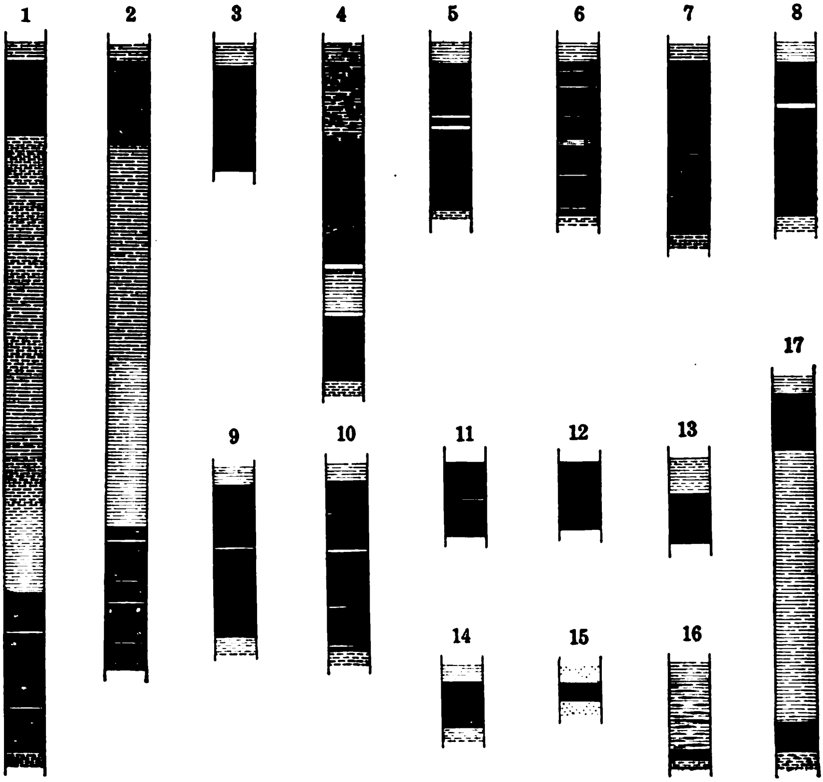


FIGURE 12.—Sections of Clarion and Mercer coals. Scale, 1 inch = 5 feet.

Clarion coal: (1) 1½ miles west of Foxburg. (2) 1 mile south of Foxburg. (3) 1 mile southwest of West Monterey. (4) One-half mile south of Bruin.

Lower Clarion coal: (5) 1 mile west of mouth of Clarion River. (6) One-half mile southwest of Parkers Landing. (7) One-half mile northwest of Parkers Landing. (8) 1½ miles southwest of Bonus. (9) One-half mile northeast of Stonehouse. (10) 2 miles southwest of Parkers Landing. (11) 2 miles southwest of Parkers Landing, 100 yards from section 10.

Upper Clarion coal: (12) Parkers Landing. (13) 1¾ miles west of Parkers Landing. (14) Stonehouse.

Mercer coal: (15) River bluff opposite Emlenton. (16) 1½ miles southwest of Parkers Landing. (17) 1 mile south of Parkers Landing.

The Upper Clarion coal is not so persistent as the Lower Clarion coal, but it underlies a large area and its outcrop is parallel to that of the Lower Clarion. Throughout much of their extent the coals are so close to each other that they can not be mapped separately on the scale used in this report. Where the coals are far enough apart and the Upper Clarion is workable, it is mapped separately. Thus, the outcrop of the Clarion coal is represented on the map by a line, which, in many places, is double.

On account of its great extent and desirable thickness, the Lower Clarion coal is the most valuable coal in the district. It contains many masses of marcasite ("sulphur balls") and several thin partings, but it is possible to remove much of the impurities by washing, and it may be that the iron sulphide might be turned into a source of profit, for iron sulphate or copperas and sulphuric acid are readily made from the sulphide.

The thickness of the coal bed varies from 20 inches to 60 inches, and averages perhaps 45 inches. The overlying stratum is shale, commonly somewhat clayey and overlain by the under clay of the Upper Clarion coal. The Lower Clarion coal rests upon a fire clay which is several feet thick and appears to be of good quality. It is firm enough to make a good floor in coal mines.

In this district the Upper Clarion coal is somewhat variable in quality. In many places it is excellent and contains few impurities, but elsewhere it is bony and shaly and in a few places contains considerable pyrite. Where present its thickness ranges from 1 inch or less to 20 inches. It is overlain by shale, which, in turn, is overlain by sandstone, clay, or limestone. The stratum under the coal is clay or shale. In some places the shale above and below the Upper Clarion is nonfissile and might more properly be classed as a mudstone. The sections given in figure 12 illustrate the character of the Clarion and Mercer coals.

Lower Kittanning coal.—North of Bear Creek the Lower Kittanning coal is not persistent and where present is thin and contains much clay and shale, so that it is practically worthless. However, it is well developed in the vicinity of Petrolia and eastward to the river. It outcrops along Pine, Cove, and Whisky runs and along Allegheny River, and its tributaries, which are small, and extends nearly 2 miles up Binker Valley.

In the southern part of the district the Lower Kittanning coal ranges from 18 inches to 38 inches in thickness and is of very good quality. The coal is overlain generally by shale, but in some places by sandstone, either rock making a very good roof. The underclay is thick and soft where weathered, but unweathered parts are fairly firm. The sections shown in figure 13 are typical.

Middle and Upper Kittanning coals.—These coals are not persistent and where present are generally worthless, but each in one or two places attains minable thickness and quality. The Middle Kittanning coal is seen and recognized at an outcrop in the road 2 miles west of Emlenton. From this point south to Bear Creek the outcrop is very devious, and the coal is of little or no value. At Bruin a coal which seems to be Middle Kittanning has been opened at several places, though none of the mines are now in operation. The bed is said to be about 30 inches thick and to have a hard shale roof and clay floor. Elsewhere the Middle Kittanning is not known to be minable and in many places is probably absent.

The Upper Kittanning coal was not seen north of Bear Creek, though a considerable territory near Bonus is high enough to contain it. This coal is very irregular in thickness, but is of fair quality. One-half mile southeast of Petrolia the coal is in a few places nearly 6 feet thick, though the upper 10 or 12 inches is bony; but within a few hundred feet the coal thins down to such an extent that it is worthless. The underclay of this coal seems to be of very good quality and more persistent than the coal. The coal is overlain by shale varying from 2 to 40 feet or more in thickness.

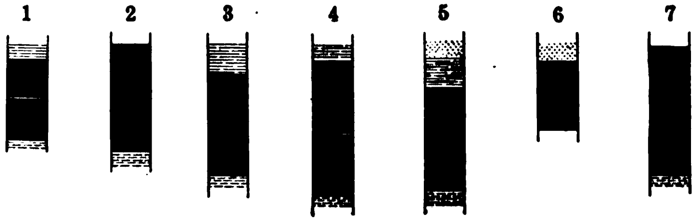


FIGURE 13.—Sections of Lower Kittanning coal. Scale, 1 inch=5 feet.

(1) One-half mile west of Parkers Landing. (2) 2½ miles south of Parkers Landing. (3) Ravine across river from West Monterey. (4) 1¾ miles south of West Monterey. (5) Queenstown. (6) Queenstown, 100 yards from section 5. (7) Cove Run, three-fourths mile southwest of Queenstown.

Lower Freeport coal.—The Lower Freeport is a fairly persistent bed in this part of the quadrangle, though it lies so high that it has been eroded from a large part of the area, its northernmost extension being found in a few isolated areas near Bonus. In this vicinity the coal is about 40 inches thick, and there are excellent outcrops, particularly on the road running northwest from Bonus. South of North Branch of Bear Creek it underlies the broad flat-topped hill upon which Glenora is situated and much of the territory between this hill and the south boundary of the area. It underlies the same area which contains the Upper Freeport but is slightly more extensive.

Throughout most of this territory the Lower Freeport is not thick enough to be worked and is commonly separated into two benches by a parting of shale. On Pine Run it is 36 to 45 inches thick and of very good quality. Elsewhere the thickness of this coal ranges from a fraction of an inch to 30 inches but is generally under 1 foot. The coal lies between layers of shale and clay, both of which are rather soft. Near West Monterey and elsewhere the shale is thin and is overlain by sandstone.

Upper Freeport coal.—The Upper Freeport coal underlies 10 or 12 square miles in this district, mostly in the southern part. There are a few small bodies of the coal in the tops of hills near Glenora, but most of it lies near the surface of the uplands south of Bear Creek. As shown by the geologic map (Pl. I, in pocket), the outcrop is extremely irregular and long. With the exception of about 2 square miles near the mouth of Bear Creek, there is scarcely an area a mile square in this part of the district that does not contain some Upper Freeport coal.

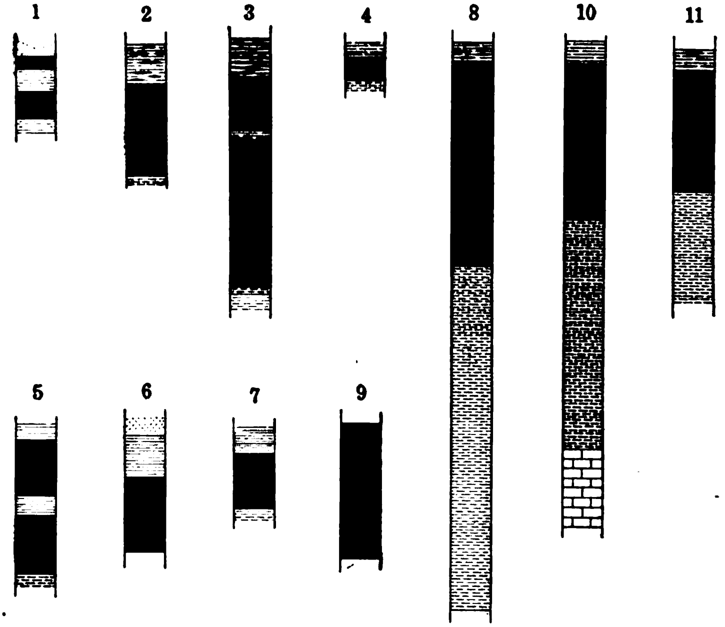


FIGURE 14.—Sections of Middle and Upper Kittanning and Lower and Upper Freeport coals. Scale, 1 inch=5 feet.

Middle Kittanning coal: (1) 2 miles west of Emlenton. (2) One-half mile southwest of Bruin.

Upper Kittanning coal: (3) One-half mile southeast of Petrolia. (4) One-half mile southeast of Petrolia, 200 yards from section 3.

Lower Freeport coal: (5) Near Bonus. (6) 1½ miles west of West Monterey. (7) 1½ miles southwest of Bruin. (8) 2 miles northeast of Petrolia. (9) On Pine Run, 3 miles east of Petrolia.

Upper Freeport coal: (10) 1½ miles southwest of West Monterey. (11) At Fairview.

The most valuable coal is found in a belt extending from Fairview and Karns City to West Monterey. Here the Upper Freeport ranges from 36 inches to 60 inches in thickness and is of excellent quality. At Karns City, just off the south boundary of the quadrangle, there are a shipping mine and several country banks. Northwest and southeast of this belt the coal generally measures under 36 inches in thickness.

West of Allegheny River the Upper Freeport coal wherever seen has a shale roof and clay floor. The bed contains very little sulphur and few bedded impurities, and it yields a better quality of coal than any other in the area. The value of the bed as a whole has been lowered by erosive processes, which have cut away much of the coal and left only irregular, more or less isolated bodies. On account of erosion also the parts of the bed that remain lie under such slight cover that they are more or less weathered, and much of the coal has so little cover that it is minable with difficulty.

The sections given in figure 14 illustrate the character of the coals in the upper part of the Allegheny formation.

STATISTICS OF COAL RESOURCES.

The following table gives the areas of each of the most valuable coal beds, and also gives rough estimates as to the territory which has been worked out and as to that which is still underlain with valuable coal:

Estimated coal resources in Foxburg quadrangle, Pennsylvania.

Coal.	Quantity before mining began.		Worked out, including waste and coal not recovered.		Minable, but not yet worked.		Not minable at present.		
							1 to 2 feet thick.		Less than 1 foot thick.
	Square miles.	*Short tons.*	*Square miles.*	*Short tons.*	*Square miles.*	*Short tons.*	*Square miles.*	*Short tons.*	*Square miles.*
Mahoning	5.00	5,000,000	0.01	10,000	0.50	1,400,000	1.00	1,600,000	3.50
Upper Freeport	20.40	59,000,000	.30	2,400,000	16.90	54,200,000	1.50	2,500,000	1.50
Lower Freeport	25.00	48,000,000	.01	10,000	8.00	27,000,000	11.00	18,000,000	6.00
Upper Kittanning	48.00	58,000,000	.01	10,000	5.00	13,000,000	18.00	31,000,000	25.00
Middle Kittanning	120.00	169,800,000	.05	200,000	7.95	19,000,000	85.00	135,000,000	27.00
Lower Kittanning	138.10	393,300,000	2.90	10,800,000	98.10	337,500,000	21.40	36,000,000	15.70
Upper Clarion	144.80	338,000.000	.20	65,000	100.00	260,000,000	35.00	72,000,000	10.00
Lower Clarion	168.10	689,200,000	1.10	5,200.000	145.00	650,000.000	15.00	29,000,000	7.00
Craigsville	80.00	75.000,000	.02	70.000	10.00	25,000,000	15.00	22,500,000	55.00
Brookville	164.10	182,500,000	.01	10,000	6.50	16,000,000	96.00	144,000,000	61.60
Mercer	170.00	70,000,000	.01	10,000	.01	10,000	12.00	17,000,000	158.00

It should be borne in mind that in the areas which have been mined out a large part, probably half or more, of the coal still remains in the ground, having been left as pillars, waste, etc.

Figure 15 shows diagrammatically the amount of territory formerly underlain by each of the eleven coal beds which were anywhere of workable thickness and also their positions in the stratigraphic column.

The sides of the diagram are so drawn as to indicate the area underlain by each of the strata above the base of the Pennsylvanian series. The upper point represents the highest stratum present within the quadrangle.

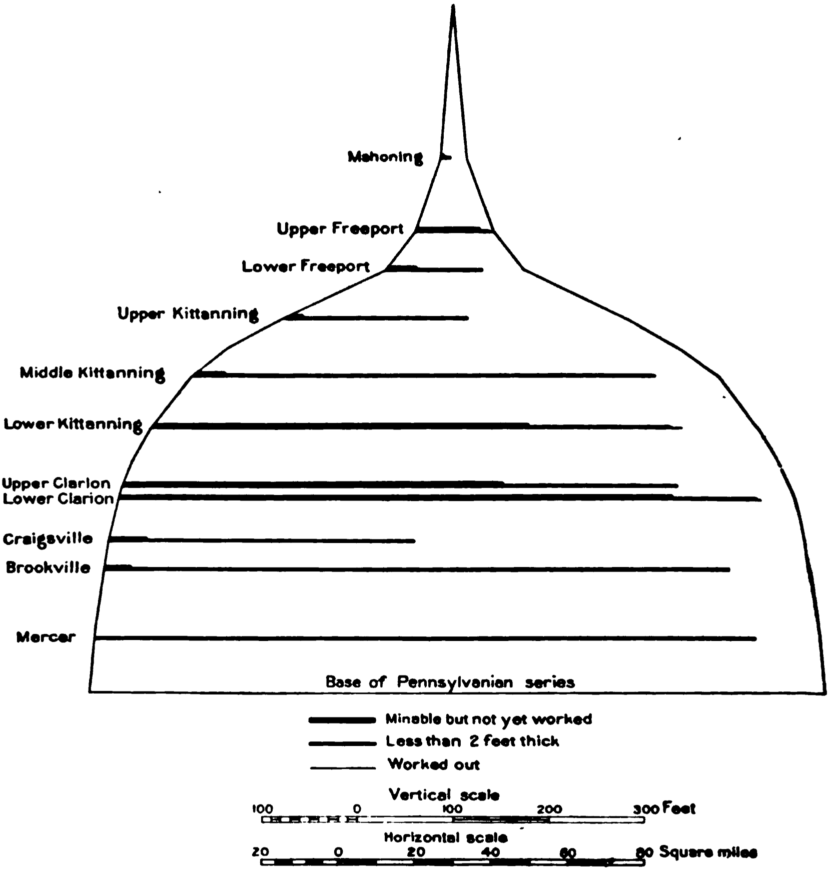


FIGURE 15.—Diagram showing areas underlain by and stratigraphic positions of the coals in the Foxburg quadrangle.

From this figure it will be seen that only a small area—only a few square miles—is not underlain by any coal.

TECHNOLOGY.

SHIPPING MINES.

In the Foxburg quadrangle there are ten active shipping mines, the individual output of which in 1908, according to the Pennsylvania Department of Mines, ranged from 6,768 short tons to 105,030 short tons, the total output being 400,263 tons.

The average individual production of the bituminous coal mines of western Pennsylvania in 1908 was 88,413 tons. The mines of the

Foxburg quadrangle have, therefore, about half as large an average production as that of the mines of western Pennsylvania as a whole.

Since the coal beds lie well up in the hills and the principal railroad lines are in the bottom of the deeper valleys, most of the shipping mines are high above the railway track level. The coal must be let down by inclines, the descent in many cases being 200 or 300 feet. All of the mines along Allegheny River are of this type. At St. Petersburg, near Clarion River, there is a mine which is just at tipple height, so that the mine can be operated without incline or hoist, and near Sligo there are two mines, one having a drift and the other a slope opening, in which the coal lies considerably below the level of the tipple.

All of the mines are above drainage, and no difficulty is experienced with either gas or dust. Most of the mines use fans exclusively for ventilation, the fans being 8 to 12 feet in diameter and having blades about 3 by 4 feet. The number of revolutions of each fan per minute varies from 55 to 110, and the amount of air driven into the mine from 4,000 to 18,000 cubic feet per minute. Two of the mines have furnaces for ventilation. One of the furnaces has 12 square feet of furnace bars and the other 24 square feet. Undercutting machines are generally used, the number in each mine varying from 2 to 14, and the coal is shot down with black powder. A small quantity of dynamite is used for brushing the entries. Compressed air is used exclusively for operating the machines and for drilling. Sulphur balls and partings are discarded by the loaders and the coal is brought to the surface by mule, cable, or motor power. The room-and-pillar system is used in all the mines. In most mines the pillars are drawn soon after working out the rooms, but in others the pillars are not drawn. The rooms average about 21 feet wide, the gangways about 9 feet, and the pillars are about 16 feet thick. The underclay is generally soft and thick, and it is necessary for the mine operators to exercise considerable care to avoid "squeezes."

The number of men employed, both inside and outside, at each mine varies from 40 to 150, the total for the 10 mines being 806, and the average number of days which each mine worked in 1908 was 188. Thus the average production per man per day was a little over 2½ short tons. The average production for each man inside the mines would be somewhat higher, for only 689 of the 806 employees worked inside.

COUNTRY BANKS.

Much coal is mined in country banks and sold at 4 to 6 cents a bushel, or $1 to $1.50 per ton, for local domestic and steam purposes, a considerable quantity being used in connection with drilling for oil and gas. However, much natural gas also is used for house heating and power and the local demand for coal is thus not so great as it would otherwise be. Not more than 2 or 3 men work in each mine. The coal is generally hand picked, forked into 1-ton or 1½-ton cars and pushed by hand out to the tipple. There seems to be a growing demand for the slack or fine coal, which was formerly wasted. Aside from taking out the slack, the coal is not screened.

OIL AND GAS POOLS OF THE FOXBURG QUADRANGLE.

By M. J. Munn.

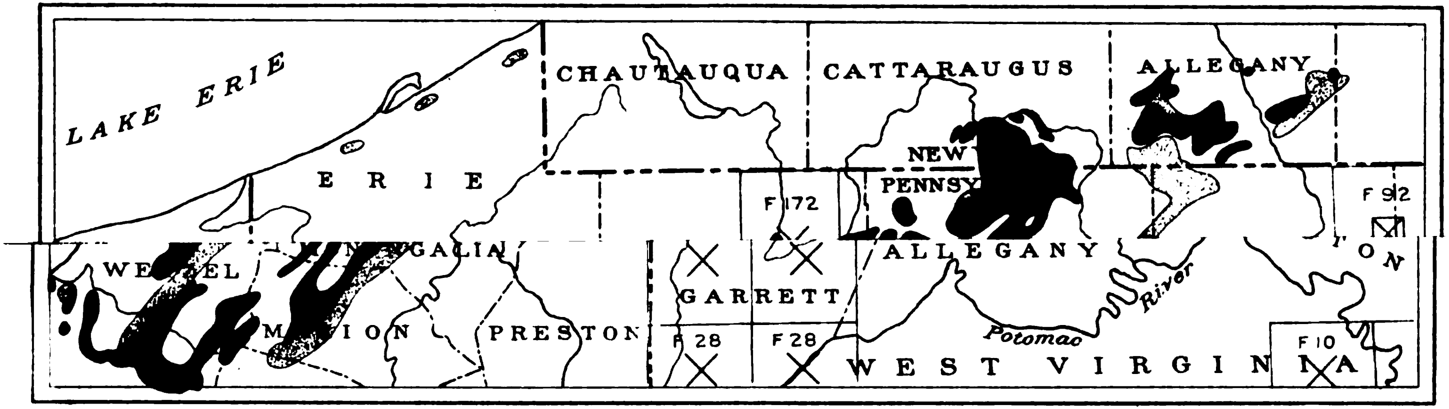
INTRODUCTION.

From the accompanying map (Pl. X) it will be seen that most of the Foxburg quadrangle has been thoroughly tested by deep wells for oil and gas. These have developed a large number of pools, more or less completely cut off from each other by unproductive or untested areas. Taken collectively, however, these pools cover a large portion of the northwest half of the quadrangle, forming two broad and fairly distinct belts trending from northeast to southwest across that area and making up one of the large and prolific oil fields of the Appalachian region. (See Pl. IX.)

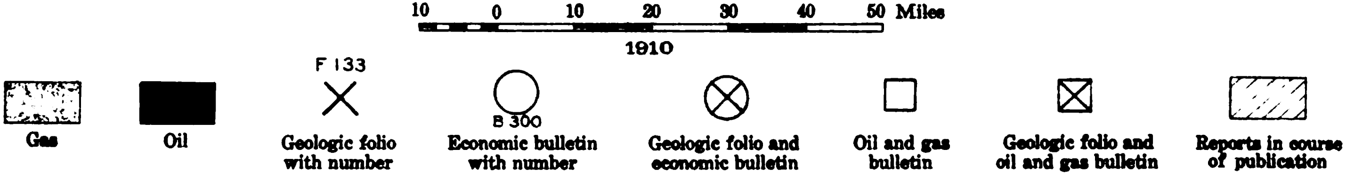
The greater number of wells of this field have been producing for twenty to thirty years and much of the geologic data available when they were drilled has since been scattered and lost. At the present time, therefore, it is very difficult to secure material sufficiently accurate to justify an attempt to work out in detail the geologic history of these remarkable accumulations.

In former studies of oil and gas pools it has been found that several determinable factors have materially affected the size and position of each. Among the more important of these factors are variations in porosity of oil sands, the degree of their saturation by salt water, and their geologic structure. In areas where much drilling has been done and where accurate records of the wells have been preserved, together with data relative to the initial conditions of flow, pressure, and capacity, the geologist is well provided with facts that when properly grouped and studied furnish reasonable explanations of some of the important phases of oil and gas accumulation, and furnish also a valuable guide to the producer in his search for undiscovered pools. The difficulty of collecting sufficient information of this kind throughout much of the Foxburg quadrangle has rendered it advisable not to attempt more than a preliminary examination of this region and to confine special studies of oil and gas phenomena to more favorable fields.

In the Foxburg quadrangle no less than six distinct sandstones produce oil in commercial quantities. Named in decreasing order of their productiveness these are the Third, Fourth, Hundred-foot



SKETCH MAP OF WESTERN PENNSYLVANIA AND PARTS OF OHIO, WEST VIRGINIA, MARYLAND, AND NEW YORK
Showing oil and gas fields, location of quadrangles, and nature of geologic reports published on each


10
0
10
20
30
40
50 Miles
1910
Gas
Oil
F 133
Geologic folio with number
B 300
Economic bulletin with number
Geologic folio and economic bulletin
Oil and gas bulletin
Geologic folio and oil and gas bulletin
Reports in course of publication

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(Second), Nineveh Thirty-foot, Bowlder, and Fifth sands. All of these have furnished more or less gas, and in addition gas has been found in the First, Big Injun, Tiona, Speechley, and Bradford (?) sands. By far the greatest amount of oil has come from the Third, Fourth, and Hundred-foot (Second) sands, and to these are accredited most of the enormous supply produced by the Petrolia-Bruin field in the southwest part of the quadrangle and the Foxburg-Elk City and the Emlenton-Richey Run fields.

In the following brief discussion of the pools by townships some of the salient geologic features of these pools will be pointed out.

DESCRIPTION BY TOWNSHIPS.

ELK TOWNSHIP, CLARION COUNTY.

In the northeast corner of the Foxburg quadrangle is included a small part of Elk Township. This area is all within the productive belt of the Third sand which, in this vicinity, is known as the Elk City pool. Oil was first discovered here in 1874 or 1875, and the greatest development work occurred in the following three years. The production came mainly from the Third sand, which furnished many wells having a capacity ranging from 100 to 500 and, rarely, 1,000 barrels per day. The average initial production for the entire pool in the early stages of its development was perhaps not more than 60 barrels per day. The Third sand has a thickness of from 10 to 40 feet, with relatively thin streaks of pay sand. It is usually separated from the Fourth sand below by from 5 to 20 feet of shale, but in a number of places the two sands appear to be united with a thin streak of dark, hard sandstone, marking the division.

In general the Third sand furnished no salt water with the oil in the early stages of pumping, the Fourth being the salt-water sand. In a number of places, however, the Third sand produced salt water with the oil from the beginning, the water decreasing in volume with pumping; in these wells the quantity of the oil depended apparently upon the quantity of salt water produced, as the oil became exhausted with the salt water. This fact is in marked contrast with the salt-water conditions in the Third sand farther to the south in Allegheny and Washington counties. In those areas no salt water is pumped from new wells, and in many places the yield of oil is checked and eventually completely cut off by an invasion of salt water.[a] Only a few of the large number of wells drilled in this portion of Elk Township are now producing. Some of them, however, still furnish from 1 to 2 barrels per day after more than a third of a century of constant pumping.

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[a] Munn, M. J., Bull. U. S. Geol. Survey No. 318, 1907; oil and gas bulletin of Sewickley quadrangle (in preparation); and Rept. Pennsylvania Top. and Geol. Survey Comm., 1906-1908.

BEAVER TOWNSHIP, CLARION COUNTY.

Most of the northwest half of Beaver Township lies in the Third sand field, which stretches in a broad belt from Petrolia to Elk City. In Beaver Township hundreds of wells formerly producing from this sand have since been exhausted and abandoned. At the present time it is impossible to find the locations of a large number of these wells, and for this reason there are many small unproductive areas within the limits of the field, as indicated on the map, that can not now be outlined with even a fair degree of certainty. During the early days of the development of this immense field hundreds of wells were drilled which furnished a few barrels of oil per day, but owing to the low price of oil and the frantic endeavor of producers to make big strikes these holes were abandoned. At that time no reliable maps of the pools were available and little or no attempt was made by the producers to preserve detailed logs of the wells. The data thus lost materially added to the cost of later development, since in many cases unproductive wells have been drilled where it was later discovered that previous holes had been of no value. Doubtless, in other cases, the report of a dry well has prevented the complete development of that portion of the pool in which it was located. Much of this area has been drilled the second time, the higher price of oil and the use of the gas engine for pumping rendering it possible to pump wells at a profit which produce from half a barrel to 2 barrels of oil per day.

Although most of the oil produced in this township has come from the Third sand, the Fourth, and Third stray sands have also furnished considerable quantities.

All of the oil-producing area has furnished more or less gas, varying from only a show in some wells to several million cubic feet per day in a few of the best. As a rule the gas wells were small producers, ranging from 25,000 to 50,000 cubic feet. Southeast from the oil pools in this township the Third sand is said to pinch out within a short distance and the Fourth to become hard and close with few porous streaks of pay sand.

The exact outline of the area in which the Third sand is wanting is not known, but from the available data it seems to be little more than a hard, close sandstone "shell" in most, if not all, of the southeastern part of Beaver Township.

The Speechley sand has been found to be gas bearing at a number of places in Beaver Township. With a few exceptions, however, the wells are light producers, though the closed pressure of the gas ranges from 500 to more than 900 pounds to the square inch. In the George Hanst No. 1 well at Wentlings Corners this sand is 30 feet thick, and was reached at a depth of 2,060 feet. Some oil was found in the

Third sand in this well, but the production was small; and the well is believed to be at or near the southeast edge of the pool. The distance from the top of the Third sand to the top of the Speechley, as given by the record of this well, is 865 feet. This distance seems to be too small for that between the Speechley and the Third sands, but there are not sufficient data available to determine the exact stratigraphic position of the gas-bearing bed. In the Thomas Wentling No. 1 well in the same vicinity the gas-bearing bed said to be Speechley is 14 feet thick and lies at a depth of 2,111 feet. A well on the D. V. Kline farm, northwest of Ritt station, in Beaver Township, found gas in the Speechley sand at a depth of 2,036 feet, the sand being 13 feet thick. In this well the Third sand is 40 feet thick and has produced some oil. The interval between the tops of these two sands is 946 feet. The Fourth sand is 14 feet thick and separated from the Third sand above by 6 feet of shale. A well was drilled in 1908 on the G. A. Hahn farm, about 1 mile southeast of Canoe Furnace and just off the eastern edge of the quadrangle, which found a light flow of gas in the Red Valley sand, which is a local name for a division of the Hundred-foot sand, at a depth of 870 feet and a small amount in the Bowlder sand at 992 feet, and also in the Speechley at 1,904 feet, the thickness of the latter sand being given as 66 feet. The gas from the shallow sands in this well has a closed pressure of about 150 pounds per square inch and is used in the residence of Mr. Hahn. That from the Speechley has a pressure of 800 or 900 pounds and hence can not be used in the same line. The volume is too small to justify piping to a commercial line, and at the time of the writer's visit this gas was blowing off into the air unchecked.

About 1 mile south of Wentlings Corners is a group of four wells which produce gas. No data are available relative to the horizon from which this gas comes. It is said that a good show of oil was found in the Third sand here and that some of the wells still flow a few barrels per month. This seems to be the most southeasterly producing area in the Third sand in Beaver Township. Other wells in this vicinity report little or no Third sand.

SALEM TOWNSHIP, CLARION COUNTY.

A portion of the Petrolia-Elk City oil belt crosses the southeast corner of Salem Township, in which it is known as the Triangle Pool. This is in reality a field composed of oil pools in the Third and the Fourth sands and a gas pool in the First sand. The Third sand produces over the entire area, the Fourth only over the northwestern portion. The First sand carries more or less gas in all parts of the field.

One of the first wells driven in this vicinity was the D. M. Delo No. 1, in 1872 or 1873. It is said that this well was a light producer from the Third sand. The field was mostly developed between 1873 and 1880, the best wells starting off at 100 to 200 barrels. Many of these old wells still produce from half a barrel to 3 barrels per day after more than 30 years of constant pumping. Others equally as good at first have long since been abandoned. Some portions of the field were abandoned before the wells were exhausted because of low price of oil at the time or of greater attractions in other pools. Later, when prices were better, some of these old holes were cleaned out and pumped again, and other wells were drilled between the locations of old wells. Some of the new wells began at 15 to 30 barrels per day; most of them, however, produced less than 10 barrels, running as low as 1 to 2 barrels per day. Taken as a whole, redrilling has been sufficiently profitable in this section to justify in places a third set of holes being put down. On the map but a small per cent of the entire number of wells are shown, most of these being wells that are now producing.

Northwest of the Triangle oil field is a continuous belt of unproductive territory, separating it from the northeastern extension of the Richey Run field, which in Salem Township is usually designated as the Salem and the Mariasville pools, both of which produce from the Third and Bowlder sands. Within this unproductive belt a few pools of oil have been found in the Third sand, but the total production from these pools has been very small. The gas wells located in this belt generally produce from the Second sand, though more or less gas has been found in the First, Bowlder, Speechley, and Third sands.

In the extreme northeast corner of Salem Township a small oil pool on the Exley and Snyder farms is said to produce from the Fifth sand, but no records of wells from this pool could be secured and therefore no definite correlation can be made. The pool was small, but furnished several good wells, a few of which flowed. After 20 years not more than five or six wells are now being pumped, and the total production is probably less than 10 barrels per day.

The gas from the group of wells to the north and northeast of Lamartine and the scattering wells in that vicinity comes from the First, the Second, the Stray, or the Bowlder sand, the principal gas horizon being the Second sand.

Most of the oil in the Salem and Mariasville pools comes from the Third sand, but the Bowlder sand carries oil at several places, the largest pool probably being at Lamartine.

Little or no salt water appears to be present in the oil-bearing sands of Salem Township. The Third sand seems to carry no water, though data on this point are not sufficient to justify a definite statement. In a few places outside the producing areas a small amount of water is reported in this sand.

The Second sand, usually a water-bearing bed in the oil region, is reported to be dry over much of the Foxburg quadrangle. From the data in hand it is not possible to outline carefully the salt-water areas in these sands, but it seems safe to say that none of them are uniformly saturated with salt water over large areas. Only a small per cent of the wells are cased below the Big Injun or Mountain sand.

RICHLAND TOWNSHIP, CLARION COUNTY.

The Petrolia-Elk City oil belt passes diagonally across Richland Township from northeast to southwest. This productive area is about 1½ miles in width and contains a large number of small pools, most of which are in the Third sand, though the Fourth and Bowlder are also oil bearing, and there are also a few wells in the Second sand. As in the townships already described, these pools also have been developed for a long time. The wells are now almost exhausted and comparatively little drilling is being done. In a few places an occasional well is put down as a cautious extension of some favorable area, but most of the development work is that of redrilling old pools that have been abandoned as exhausted. It is found that many of these pools really contained an enormous amount of oil when the former wells were abandoned. New wells in this territory that start at from 3 to 6 barrels per day are not uncommon, and they are found to run down very slowly in production, due to the small gas pressure behind the oil.

It is not possible with the data in hand to outline each of the pools in the Bowlder, Hundred-foot, and Third sands. Considerable areas of the Bowlder and Hundred-foot sands in the vicinity of Alum Rock and northwest from that place were oil bearing. Between this portion of the field and St. Petersburg is a comparatively barren strip in which the wells were small or unproductive. From St. Petersburg to the edge of the township at Foxburg the Third and the Hundred-foot sands have been prolific along a narrow belt lying between the Foxburg-Petersburg pike and Clarion River.

Through the central portion of Richland Township extends an unproductive belt from 1 to 2 miles wide in which a few scattering wells have produced a little oil and gas. Along the northwest margin of the township is a narrow line of productive territory belonging to the Richey Run field, in which the oil comes from the Third sand. In the extreme northeastern part of the township in the vicinity of Martin's mill a number of fair gas wells have been secured in the Speechley sand. Some of these wells have shown oil in the Second sand and some gas in the Third sand.

RICHLAND TOWNSHIP, VENANGO COUNTY.

The Richey Run oil field in the Third and the Bowlder sands extends across the entire southern border of Richland Township, Venango County. This field has been a very prolific one in the Third sand, having furnished many wells ranging from 100 to 500 barrels per day. Along the northern edge of the field several small pools occur in the Bowlder sand, the exact outlines of which could not be determined. It is said that the Fourth sand has also produced some oil in this field, but the amount was relatively small. Over most of the Richey Run pool the Third sand is less than 25 feet in thickness; the average is probably not more than 15 feet. The total production, however, has been great, and many wells continue to produce after twenty to thirty years of constant pumping. The Bowlder sand ranges from 5 to 20 feet, with an average thickness of about 12 feet. While wells in this sand have not, as a rule, been large, they hold up well.

On Plate X a considerable area to the northwest of the Richey Run oil field is shown to contain a number of scattering gas wells. Most of them are light producers from the Second sand. The Speechley, Third, Bowlder, and First sands also produce considerable gas in this area. The closed pressure varies from less than 100 pounds in the First sand to more than 800 pounds in the Speechley. This pressure seems to vary greatly from well to well in the same sand, and in the Speechley the range is from about 300 to more than 800 pounds. This is due to some extent, undoubtedly, to the partial exhaustion of gas in some areas, and the consequent reduction of the closed pressure, but in a few places recent wells showing a high closed pressure are surrounded by previous wells of a lower initial pressure; this seems to indicate strongly that the original closed pressure of the gas at various points in the sand was not the same. Unfortunately, sufficient data on this point could not be secured to enable the writer to arrive at any definite conclusion regarding this phenomenon.

Within this gas belt a number of wells have shown more or less oil in the Bowlder and Third sands, but only in a few places in commercial quantities. One of these pools in the Third sand occurs on the farms of J. L. Beals and J. A. Creswell, near the northeast boundary of the township. Several of these wells flowed from the Third sand. Gas was also found in the First, Second, and Speechley sands. A small pool of oil was found in the Bowlder sand south of Keefers Mill on the Bly farm. The oil came from five or six wells, and the total production was very small. Some of these wells are still producing. Gas is here found in the Second and the Speechley sands.

ROCKLAND TOWNSHIP, VENANGO COUNTY.

Only a small portion of Rockland Township is included in the northwest corner of the quadrangle. Within this area the Black Hill oil pool has been developed in what is locally known as the Red Valley oil sand. This pool is about 2 miles long by three-fourths mile maximum width. The major axis extends in a northeast-southwest direction, with Black Hill near the southwest margin. The first wells in this pool were drilled in about 1873 on the Samuel Batton farm, but they were small producers and attracted little attention. The greatest development took place ten or twelve years later, when a well on the Jolly farm came in at about 200 barrels per day. From this time forward the development was rapid. Many wells had an initial production of more than 100 barrels per day. These wells are now exhausted and abandoned. A few of the less-productive wells are still being pumped after 25 years, but they probably average less than one-half barrel per day each. Redrilling has developed a few producers of 1 to 3 barrels each, which show remarkable steadiness of production; the field as a whole, however, is practically exhausted, though there is some reason to believe that a few wells will continue to be pumped for years. These can be profitably operated because of the high price of oil and the low cost of pumping. This is achieved by shackling a number of wells to a single gas engine, which in turn is run by gas drawn from the wells. This pool has been encircled by holes, but no other oil has been found in that portion of the township lying within the quadrangle.

SCRUBGRASS TOWNSHIP, VENANGO COUNTY.

The Emlenton-Richey Run oil field, producing from the Third and the Bowlder sands, crosses the southeastern corner of Scrubgrass Township in the vicinity of Emlenton. At this point it is about 2 miles wide from north to south and contains a number of small barren areas in both the sands. The Third sand is productive at various points over the entire area, but most of the oil in the Bowlder sand is confined to the northern half of the belt. Northwest from this oil belt the Third sand is reported thin or absent. The Bowlder is present here in normal thickness, and has been found to contain some gas, but no oil. Most of the gas is derived from the Second and the Speechley sands. The gas wells, however, are few in number and of small capacity, though they usually produce for a long time.

ALLEGHENY TOWNSHIP, BUTLER COUNTY.

The Emlenton-Richey Run oil field occupies considerable territory in the northern part of Allegheny Township. In this area the production is mostly, if not all, from the Third sand. South of this field stretches the broad belt of unproductive territory from northeast to southwest across the quadrangle, separating it from the Petrolia-Elk City oil belt. At the southern edge of this unproductive belt is the Rosenberry pool, the largest oil-bearing area yet discovered in the Hundred-foot (Second) sand within the quadrangle.

From the incomplete records at hand the Second sand seems to range from 20 to 100 feet in thickness within the limits of this pool.

The oil is apparently always accompanied by more or less salt water, which decreases with pumping, the oil becoming exhausted with the water. In this pool some wells have found oil in the Third sand, but this sand is barren over much of the pool, especially in the northern part. Toward the south in this pool the Third sand is more commonly productive.

Southeast of the Rosenberry pool is the "Sucker-rod pool," in the Hundred-foot (Second) sand, a very narrow pool having an almost north-south trend for more than 1½ miles, its average width being less than 800 feet. The remainder of the oil produced in these townships comes from the Third sand, with the possible exception of that from a few scattering wells in the Bowlder sand.

HOVEY TOWNSHIP, ARMSTRONG COUNTY.

Hovey Township embraces a narrow strip of country lying between the Butler County line and Allegheny River, north of Bear Creek. In this township were drilled in 1869 the first wells of the Petrolia-Elk City pool. Some of these wells, located on the Reddick farm, had an initial production from the Third sand of more than 100 barrels per day. Of these wells Reddick No. 3, known as the "Buckhorn" well, drilled in 1869, is still producing about one-half barrel per day, after forty years. The Third sand in this vicinity is from 15 to 35 feet thick, with 2 to 10 feet of porous pay streak. The entire township lies within the productive areas of the Third and Second sands with the exception of the extreme northern end, which seems to be in the barren belt. The conditions of the oil sands in this area are similar to those described for Allegheny County, and need not be repeated.

PERRY TOWNSHIP, CLARION COUNTY.

Perry Township embraces a considerable area of the Third sand oil pool along the northwestern border. In this vicinity the Bowlder sand also produces oil in a few wells. A sand, about 300 feet above the Third, which is locally known as the Red Valley oil sand, and which is a part of the Hundred-foot sand, is also oil bearing in a small pool east of the mouth of Clarion River.

Many of the Third sand pools in the township have been developed for a long time, and a large per cent of the first wells have been exhausted and abandoned. These are not shown on the map, and were not located in the field, so that it is not possible to distinguish originally barren areas from abandoned pools within the productive belt. Without that belt, and especially in the eastern and southern portions of the township, considerable care was taken in the field to locate all the holes that have been drilled.

From the map (Pl. X) it will be seen that the Second sand furnishes a few small pools along Allegheny River from the extreme southern edge of the township to half a mile below the mouth of Bear Creek. Data relative to these pools are meager. Many of the wells have been exhausted and abandoned, and the border of the productive area can not now be exactly determined.

In the remainder of the township no oil pools of consequence have been found, though small shows of oil were secured in a number of gas wells shown on the map. Most of the gas in this township, outside of the Third sand oil field, comes from the Speechley sand. In well No. 17, drilled in 1908, on the Terwilleger farm, it should be noted that gas was found in the Third sand at a point where it is 34 feet lower than the nearest oil pool in that sand. As a rule, the gas wells of this township have not been large producers, though the closed pressure ranges from less than 100 pounds in some of the shallow sands to as much as 800 or 900 pounds in the Speechley. As a rule, however, the gas wells continue to produce for relatively long periods, and the closed pressure decreases slowly.

LICKING TOWNSHIP, CLARION COUNTY.

Licking Township shows a remarkable contrast with the townships lying to the north and west as regards oil pools. Structurally this area seems to be as favorably situated for accumulations of oil as that of Beaver, Richland, or Perry townships, but from what could be learned the Third and the Fourth sands, from which so much of the oil comes, seem to be absent from a considerable portion of Licking Township, and are thin and of poor quality over all or nearly all the remainder. Within this township not more than 40 wells have been drilled. Of these probably less than 10 have shown indications of oil. One of the best indications was found on the Jessie Best farm near Turnip Hole, from which were pumped a few barrels of oil per day for several months from the Third sand. The John Black No. 1 well in this vicinity is said to have had a good show of oil in the Hundred-foot sand. Gas comes principally from the Hundred-foot and the Speechley sands, neither of which are large producers. In the limited time devoted to field work on this township considerable attention was given to locating on the map as many of the test wells drilled therein as could be found, and it is believed that at most only a few were overlooked. The map shows comparatively large areas yet untested, but on the whole the chance of finding a good quality of oil-bearing rock in either the Third or the Fourth sand in these areas is not encouraging, for sandstones of this type are very changeable as regards porosity. It is possible, however, that good porous pay streaks exist here which contain pools of oil and gas. It such pay streaks exist within this township the western portion will very probably be found to carry most of the oil.

PINEY TOWNSHIP, CLARION COUNTY.

In the small portion of Piney Township included in the quadrangle no oil or gas pools have been discovered and no wells are known to have been drilled. A short distance farther to the east, in the vicinity of Sligo, considerable quantities of gas have been found in the Second sand, and it is possible that future development will show a portion of this pool extending into the quadrangle along Licking Creek.

TOBY TOWNSHIP, CLARION COUNTY.

With the exception of a small pool in the extreme western end along Allegheny River, Toby Township has produced no oil in the Foxburg quadrangle. This pool contained only a few wells, none of which were large producers. All of the oil comes, it is said, from the Hundred-foot sand. The pool is now exhausted and all the wells are abandoned.

A number of fair gas wells have been brought in along the southwest border of this township, though none of them were very large. The gas is found principally in what is variously called Hundred-foot, Thirty-foot, and Second sand, but its correct name can not be determined from the few records available. In several of the wells the Bowlder and the Speechley sands are said to furnish gas.

Several wells drilled along Cherry Run have produced some gas from what is called First and Second sands. The wells northwest of Toby were small and of little value. Near the camp ground 1 mile west of Huey a well was drilled about 27 years ago which produced an enormous flow of gas from what is called Second sand. This well, it is said, caught fire and blew into the air for a year or more before it was put under control, the flame reaching to a height of 100 feet or more. Later a number of other wells were drilled around it and a considerable gas pool was developed. Some of these wells are still producing.

The map (Pl. X) shows most of the wells drilled in Toby Township, if not all of them. It will be seen that this area is by no means fully tested. Poor sands rather than unfavorable structural conditions have discouraged drilling. Of these, the Third sand is absent in some places and is but a thin, hard "shell" in other places. It is not known that the Third sand carries a porous pay streak at any point in the township, though there are, very probably, small areas where it is open and porous. So far as could be learned, the other sands have about their usual thickness and texture, except that the Bowlder and the Fourth sand are thinner and less porous than they are in the quadrangle farther to the northwest.

MADISON TOWNSHIP, CLARION COUNTY.

Only the northwestern portion of Madison Township lies in the Foxburg quadrangle. This part has produced but little oil or gas. In the extreme western end of the township, on Allegheny River, a number of wells produce oil from the Fourth sand. This is the western edge of the great "Cross Belt" from Petrolia to Allegheny River, described under Perry Township, Armstrong County.

Eastward from this field the Fourth sand is frequently gas bearing. In a few wells a small quantity of oil also has been found. The Fourth sand here contains most of the gas pools yet discovered in this area, but a number of wells produce gas from the Fifth, Bowlder, First, and Hundred-foot sands. The Third sand is thin or wanting over most of the area, especially toward the eastern edge of the quadrangle. The gas wells, as a rule, are of medium capacity, but they usually hold up well, both in capacity and closed pressure. Owing to the limited time at his disposal, the writer was unable to secure much data relative to initial closed pressures. As a rule, the sands above the Fourth carry an initial pressure between 50 and 400 pounds. In one well the initial closed pressure in the Fourth sand is reported at 500 pounds. No data relative to conditions of the Speechley, Tiona, and so-called Bradford sands were obtained.

BRADYS BEND TOWNSHIP, ARMSTRONG COUNTY.

Only a narrow strip along the northern edge of Bradys Bend Township is included in the quadrangle. A portion of this area in the vicinity of Allegheny River and as far west as Cove Run produced a large amount of oil during the "Cross Belt" oil excitement of 1874–75. Some of the wells in the vicinity of Queenstown are said to have had initial productions of 500 to 2,000 barrels per day from the Fourth sand. These wells were comparatively short lived and have long since been exhausted and abandoned. The Fourth sand is reported to be from 10 to 40 feet thick, averaging about 20 feet, over most of the area. At the present time a few wells drilled in later years are being pumped and an occasional well is being put down as a test of the old territory.

PERRY TOWNSHIP, ARMSTRONG COUNTY.

The accompanying map (Pl. X) shows scattering oil wells around almost the entire border of Perry Township. These wells are only a small portion of the number that have been drilled within the area, nor do they adequately cover the territory from which oil has been taken. Probably the first oil wells in the township were drilled in the vicinity of Parkers Landing in 1870. On April 20, 1870, a well was completed on the J. L. Mildren farm, at the head of Armstrong

Run, northeast of Queenstown. This well began flowing from the Fourth sand at the rate of 2,000 barrels per day. It was the first well in the "Cross Belt" pool and created great excitement throughout the oil region. A frantic development of the pool followed and it was rapidly extended westward across the southern part of Perry and the northern part of Bradys Bend townships to the vicinity of Petrolia and Karns City. So far as known, the best well in this pool was on the Parker farm, on Pine Creek, in Perry Township, near the southern border. This well began flowing at the rate of 3,000 barrels per day from the Fourth sand. Other wells in this vicinity produced from 1,000 to 2,000 barrels per day.

In the meantime during 1870 and 1871 the Third sand pool in the northwest corner of the township was being rapidly developed. The average daily production from the township during the period from 1871 to 1879 is not known, but it greatly exceeded that of any other time. The following figures from Stowell's Petroleum Reporter, published by Carll,[a] gives the approximate production of the Petrolia-Elk City oil belt from 1875 to 1879, inclusive:

Approximate production Petrolia-Elk City oil field, 1875–1879.

Date.	Number wells producing.	Average daily production.	Average daily production per well.
		Barrels.	*Barrels.*
1875	1,696	20,060	11.3
1876	2,346	14,490	8.3
1877	3,889	22,787	5.9
1878	4,650	18,730	4.0
1879	4,315	11,840	2.7

It seems very probable that a large portion of the oil from this region in the year 1874 came from Perry Township. The Fourth sand wells decreased rapidly in output, however, and many of them were down to a daily production of only a few barrels per day within two or three years. With the cheap price of oil at that time these small wells were not profitable and were abandoned. Few, if any, of the early Fourth sand wells in this pool were pumped after 20 years. The pool has been redrilled one or more times in many places for initial productions of from 2 to 20 barrels per day. A few of these later wells are still being pumped and have been noted on the map (Pl. X). Desultory redrilling is still going on with fair success.

Over the area embraced by the "Cross Belt" the Third sand is absent or unproductive. This sand thickens toward the northwest, however, and has furnished many fine wells in the vicinity of Fredericksburg and northward along the western border of the township.

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[a] Second Geol. Survey, Pennsylvania, Vol. III, p. 147.

Gas and some oil have been found in what is called Second sand at a number of places within Perry Township. Probably the largest and most profitable pool in this sand is the Rattlesnake Pool lying along Allegheny River from West Monterey to near the mouth of Bear Creek. This pool has been developed on both sides of the river, but in Perry Township the best portion of the pool was practically embraced by W. H. Harrison's farm. The best well in this portion of the pool produced about 25 barrels per day. The pool has been developed for several years and the production is now quite small. The oil from the so-called Second sand in this pool, as in those previously described in the Foxburg quadrangle, is accompanied by more or less salt water, both oil and water decreasing with pumping and both being exhausted together. This phenomenon appears to be peculiar to the Second sand in this region, little or no salt water being found with the oil in the other sands with the exception of that mentioned above in the Third and Fourth sands in Elk and Beaver townships.

PARKER TOWNSHIP, BUTLER COUNTY.

Only the eastern half of Parker Township is embraced by this quadrangle. This area is nearly all in the producing territory of the Third, Hundred-foot, Bowlder, and Thirty-foot sands. To the east of Bruin and northward along Bear Creek to the vicinity of Parkers Landing the oil is all, or nearly all, from the Third sand, though small pools in the other above-mentioned sands occur.

West of Bruin and northward along the western edge of the field the Thirty-foot and the Bowlder sands are more frequently productive in small pools, though the Third sand furnishes the greatest amount. North of Bear Creek the Rosenberry pool in what is called Second sand has furnished a large quantity of oil, where the Third sand is barren. Over much of the area west and southwest of Parkers Landing the Third sand has produced oil since 1870, and much of the territory has been exhausted and abandoned. Many of the wells now being pumped in this portion of the pool are later wells put down in retesting. Only a small portion of these wells are located on the map. The thickness of oil-bearing sands of this township is discussed under the heading Stratigraphy.

FAIRVIEW TOWNSHIP, BUTLER COUNTY.

The northeast corner of Fairview Township is included in the southwest corner of the Foxburg quadrangle. The Third and Fourth sands of this area have furnished an immense quantity of oil. The Third sand is productive in the northern portion, the Fourth sand furnishing most of the wells in the southern part. It is said that some areas in the vicinity have been redrilled two and even three times for oil left when previous wells were abandoned.

In this township the rocks below the Mountain sand carry little or no water, and in order to increase the flow of oil vacuum pumps are used to exhaust the gas and air from the hole. These pumps have been used over a large area to the east, south, and west in this township where oil is derived from the Fourth sand. The continued use of such pumps has so developed a vacuum in the Fourth sand that a new well put down 1,000 feet from wells using pumps develops considerable "suction" when the drill reaches that sand. Drillers say that this is so strong in some wells that the water used in drilling immediately disappears and in some wells, it is claimed, the bailings composed of the powdered sandstone also go with the water. When such a well is drilled in and the pumping machinery is installed it is said that frequently several barrels of oil are dumped into the hole for "priming" before the well can be made to furnish a drop of oil, after which it will continue to furnish oil for years at a rate of from one-half to 4 barrels per day. These wells are pumped with gas engines which use the gas from the wells. One of these engines is frequently geared or "shackled" to six to ten wells. In areas where vacuum pumps are used one pump supplies suction for one to three wells, depending upon the leakage, etc., and these are also operated by the gas engine. All pumps on a lease are connected by pipes so that a relatively equal suction is maintained. The machinery is run day and night and shut downs are avoided as much as possible since they are accompanied by a loss of head.

APPARENT EFFECT OF STRUCTURE ON THE ACCUMULATION OF OIL AND GAS IN THE FOXBURG QUADRANGLE.

The oil pools of the Foxburg quadrangle show no marked relation to the structure of the rocks. Individual pools appear in places to be somewhat affected by the structure, as in the Second sand of the Rosenberry pool; but these instances of apparent conformity are so rare and insignificant in comparison to the total productive territory in the quadrangle that the position and extent of such pools seem probably only slightly, if at all, the result of structural influence.

Salt water is present with the oil in the Rosenberry field, and, according to the generally accepted anticlinal theory of accumulation, the oil, under such conditions, should be found on the side or crest of an anticline, which is true of this pool. But this rule will not hold good for other pools in the Hundred-foot sand. The Rattlesnake pool on Allegheny River, north of West Monterey, is an example where the oil occurs with salt water almost exactly in the bottom of a shallow syncline. There is little or no doubt that the Hundred-foot sand is continuous between the Rattlesnake and the Rosenberry pools, though it is not oil bearing.

The great oil pools in the Third and the Fourth sands, which furnish by far the larger part of the oil in the quadrangle, signally fail to conform to the structure lines. From Plate X it will be seen that the position of the pools in the Third sand is determined to a very great extent by the thickness of the sand, which in general serves also as an index of its porosity. These pools in the Third sand can not be explained by the generally accepted anticlinal or structural theory of oil and gas. This theory, in brief, provides that, having given an open porous sandstone slightly folded and filled with a mixture of oil, gas, and salt water, the ultimate condition will be that the oil and the gas, being lighter than the salt water, will become arranged through difference in weight along the arches of the folds in the order of their gravity, the gas at the top above the oil and the salt water below the oil. In these pools no such arrangement can be detected. The oil seems to occupy all open, porous areas of the Third sand in the broad producing belts regardless of the position of the folds. This is a marked exception to the condition found over broad areas in the Hundred-foot sand farther south, where the oil pools lie remarkably parallel to the trend of the structure.[a] To add to the difficulty of providing an explanation of the Third sand pools of this quadrangle by the anticlinal theory, it appears from the data in hand that the Third sand is comparatively free from salt water throughout the entire quadrangle, except a small area in the extreme northeast corner of the quadrangle, where salt water is pumped with the oil. The salt water area in this instance is the highest structural point in the producing belt of the Third sand. This fact is in direct opposition to the idea of accumulation by difference in gravity of oil, gas, and salt water.

Most of this oil territory was developed 25 to 35 years ago and it is now impossible to collect facts that will give a clear understanding of the minor geologic details of the field, but such details are of the utmost importance in the formation of correct conclusions relative to the geologic factors that have influenced the accumulation of oil. One fact may be pointed out, however, to which some significance is attached. In this field, as in almost every other field in the Appalachian region that has been examined, a bed saturated with water, usually saline, lies at a considerable distance above the oil sand. It is believed by the writer that this persistent and almost universal feature of the stratigraphy of producing territory may be found to be an important factor in the accumulation of oil and gas.

An extended discussion of the significance of this feature need not be given here, but it may be pointed out in passing that in such a stratum as the Third sand, shown on Plate X, the oil could hardly have traveled horizontally through the sandstone so far as would be necessary to furnish an accumulation so enormous, since the dip of the rocks is so slight that if we assume that the sand once contained salt water, the maximum pressure that could have been exerted by a globule of oil toward movement up the rise in the sands must have been a very small fraction of its weight. Under these conditions it seems that this pressure would have been totally inadequate to overcome the relatively great opposing forces to be encountered by globules of oil in their passage through the water-logged pores of the sand.

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[a] Oil and gas bulletin of Sewickley quadrangle, published by Top. and Geol. Survey Comm. Pennsylvania; Bull. U. S. Geol. Survey No. 318, 1907.

If, however, we consider the force exerted by a body of water slowly soaking downward through drier, close-grained shale and sandstone from a water-bearing stratum above, it does not require a great stretch of the imagination to see that the oil and gas scattered throughout the shale mass (from which the oil of the pools has doubtless been derived) might easily have been driven ahead of the water by a combination of hydraulic and capillary pressure. Such a movement might have come as easily from below as from above, provided there was a porous water-bearing bed in that direction. In either case the body of water would continue to move from its source until the supply was disseminated, or until the hydraulic pressure was reduced to zero by friction and the capillary power was also exhausted by coming in contact with open, porous sandstones. The moving water would tend to drive ahead of it a body of oil, which would be collected from and forced out of the fine-grained rocks into the coarser more porous ones. Except where hydraulic pressure predominated no water would be visible, since the rocks would yield no capillary water to a hole drilled into them. The capillary force exerted by water in porous sandstones is much weaker than it is in the finer-grained shale. It seems possible, therefore, that oil and gas pools may occur in zones where the surface water soaking downward through practically horizontal strata loses its active or hydraulic head through friction and its capillary pressure by the change from fine to coarse pores in the rocks. The oil thus forced from the fine-grained rock may be collected into pools in the porous bed by the action of this body of water, or, after being disseminated in the porous bed, it may at some subsequent time be collected into pools by currents of water moving through the porous bed in the direction of the bedding.

This idea of accumulation of oil and gas by the movement of bodies of water under both hydraulic and capillary pressure appears to be easily applicable to all types of oil and gas pools, but the facts to substantiate it can not be readily ascertained in old producing areas like those of the Foxburg quadrangle.

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